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Electro-Optical Properties of Colloids

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INTRODUCTION

FROM the work of numerous investigators[1] it is known that many colloids, proteins, and suspensions become doubly refracting under the influence of a uniform electric or magnetic field. Plane polarized light, incident normal to the field direction, emerges elliptically polarized with a phase shift

$$\varphi = 2\pi(n_p - n_n)d/\lambda \qquad (1)$$

between the ordinary and extraordinary light components. λ is the wave-length, d the length of the effective light path. The birefringence $(n_p - n_n)$ can be positive or negative, depending on whether the refractive index n_p for light vibrating parallel to the field is larger or smaller than the index n_n for the normal light component. We shall refer to φ as the "optical shift."

The electro- and magneto-optical effects in most colloids are considerably larger than those in pure liquids. In some colloids φ reaches unusually large values, amounting to several multiples of 2π for moderately strong fields (100 volts/cm or 1000 gauss, respectively) and for path lengths of only a few centimeters. Such large effects were first discovered in magnetic fields by Majorana[2] working with colloidal solutions of ferric oxides. The discovery of anomalous electro-optical effects is more recent. They occur in the colloids of vanadium-pentoxide, in solutions of various mosaic virus proteins and they are especially large in bentonite solutions.[3] The optical effects in these colloids are termed anomalous not only on account of their large magnitude, but also because they vary in quite an unexpected and unexplained manner with the intensity and frequency of the applied field and the concentration of the solution. Since a study of these anomalous effects promises to furnish new information about size and shape, optical and electrical properties of the colloidal particles and, eventually, also about the forces acting between the micelles, we have undertaken a new study of these effects. The work was carried out mainly with sols of white and yellow bentonite. Preliminary results on tobacco and aucuba mosaic virus proteins show the same features as those for the bentonites.

[1] For reviews of the work done prior to 1930 see H. Freundlich, *Kapillarchemie* (Leipzig, 1932), Vol. 2, p. 41, and W. Schuetz, *Handbuch der Experimentalphysik* (Leipzig, 1936), Vol. 16, 1, Chapter 8.

[2] Qu. Majorana, Atti d. Reale d. Lincei, **11**, 1° sem. 374, 463, 470, 2° sem. 90, 139 (1902). For further references and results on other colloids see W. Heller, Kolloidchem. Beihefte **39**, 1 (1933).

[3] J. Errera, W. Overbeck, and H. Sack, J. de Chim. Phys. **32**, 681 (1935); H. Mueller, Phys. Rev. **55**, 508, 792 (1939); F. J. Norton, Phys. Rev. **55**, 668 (1939); H. Mueller and B. W. Sakmann, Phys. Rev. **56**, 615 (1939); B. W. Sakmann, M. S. Thesis (1939), and Ph.D. Thesis (1941), Massachusetts Institute of Technology; M. A. Lauffer, J. Am. Chem. Soc. **74**, 147 (1939).

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In this paper we shall limit ourselves to the discussion and description of the experimental method. The measurements and the interpretation of the results will be presented in subsequent papers. All previous electro- and magneto-optical investigations are based on measurements of the optical shift by means of compensators (Babinet, Soleil, or Senarmont). This procedure is justified when φ assumes a fixed steady value, as it will when the applied field is steady. The electro-optical measurements of colloids, however, cannot be carried out with steady fields because the micelles are charged and migrate to and finally flocculate at one of the electrodes. Hence the investigations must be carried out with alternating fields and the shift φ will, in general, not be steady. Thus it becomes necessary to devise a method for the measurements of variable optical shifts.

KERR EFFECT IN ALTERNATING FIELDS

Although a satisfactory explanation of the anomalous electro-optical effects in colloids cannot yet be given, there is ample evidence that an appreciable part of the birefringence is due to the orientation of the anisometric particles of the colloid. Thus, to a limited extent, the effect is similar to the Kerr effect in gases and liquids. In the latter substances an alternating field $E_0 \cos \omega t$ creates an optical shift

$$\varphi = \varphi_0 \cos^2 \omega t = \tfrac{1}{2}\varphi_0(1+\cos 2\omega t). \qquad (2)$$

This relation holds when the orientation of the particles can follow the alternations of the field, i.e., when the period $1/\omega$ is much larger than the so-called relaxation time of the particles. The relaxation time is the time required for the particles to invert their orientation and is, according to Debye,[4] of the order of magnitude $\tau = 8\pi\eta r^3/kT \sim 10^{13} r^3$, for aqueous solutions. In our bentonite colloids the average particle radius r is between 10^{-6} and 10^{-5} cm, and it follows that Eq. (2) can be expected to hold only for fields of frequency less than 100 cycles per sec. For fields of higher frequencies two alternatives are to be considered: a. If the orientation results from the fact that the particles are permanent electric dipoles, we know from Debye's theory that the orientation and, hence, also the birefringence will vanish at high frequencies; b. if the orienting torque on the particles is proportional to E^2, as is the case when it results from the induced electric moment, the average effective torque does not vanish for high frequencies, but the resulting birefringence is steady. The latter case has been discussed by J. H. Tummers.[5] It can be shown that in both cases the optical shift for an alternating field is given by an equation of the form

$$\varphi = A + B \cos (2\omega t - \psi), \qquad (3)$$

i.e., it consists of a steady part A which varies with the amplitude E_0 and the frequency ω of the field, and of an alternating part, whose amplitude B also is a function of ω and E_0. The variations of the optical shift lag behind those of the field by a phase angle ψ. Its value varies with E_0 and ω. For low frequencies $A = B$, $\psi = 0$, and Eq. (2) is valid. For dipolar orientation A and B vanish at high frequencies and ψ approaches π. For nonpolar particles A is independent of ω, B vanishes for high field frequencies, and ψ approaches $\pi/2$. It is to be expected that an equation of the above form (3) will always hold, at least as a first approximation, but our limited knowledge concerning the origin of the anomalous Kerr effect in colloids does not permit any prediction concerning the dependence of A, B, and ψ on E_0, ω, and on the relaxation time τ.

The validity of Eq. (3) for the electro-optical properties of bentonite and aucuba mosaic virus protein has been ascertained by the following experiment. A Kerr cell containing the colloid is placed in the conventional way between crossed Polaroids and is illuminated by the monochromatic light of a Hg arc, operated on 60-cycle a.c. An electric field of an intensity sufficient to create an optical shift of about $\frac{1}{2}\pi$ and of a frequency which is a small multiple of 60 cycles is applied to the cell. The transmitted light enters a photo-cell. The photo-current is amplified and recorded on the screen of a cathode-ray oscillograph, using a linear sweep of 60 cycles/sec. The steady part A of the optical shift gives rise to a $\sin^2 x$ curve, corresponding to the intensity variation of the light source. The

[4] P. Debye, *Polar Molecules* (Chemical Catalog Company, New York, 1929).

[5] J. H. Tummers, *Dissertation* (Utrecht, 1914). This paper gives the derivation of Eq. (3) for nonpolar particles.

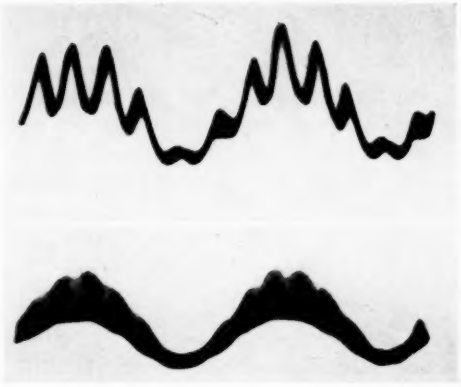

FIG. 1. Variation of the light intensity transmitted by a bentonite Kerr cell. The long period variation is due to the variation of the incident light, its amplitude is a measure for the steady part of the birefringence. The short period variation arises from the alternating birefringence. In the upper figure the field frequency is 360 cycles, in the lower 500 cycles/sec.

presence of the alternating part of φ is revealed in the photograph of the pattern, shown in Fig. 1, by the "ripple" superposed on the $\sin^2 x$ curve. The frequency of this ripple is twice that of the applied field. Its amplitude diminishes with higher frequencies. It always is smaller than the amplitude of the $\sin^2 x$ curve. This fact implies that $B<A$. If the frequency of the field is not a whole multiple of the frequency of the light source, the alternating part of φ creates a broadening of the $\sin^2 x$ curve, as shown in the lower part of Fig. 1.

Observations of this type are useful mainly for making a survey of the electro-optical behavior of a colloid, but they are not suitable for quantitative measurements. If, as is always observed, the ripple disappears at an increased frequency for all field intensities and does not reappear for still higher frequencies, one can be assured that in this frequency range the optical shift is steady, $B=0$, and A can be measured by the usual compensator methods. Depending upon the particle size and the concentration, the birefringence in bentonite reaches a steady value for frequencies between 500 to 2000 cycles. In mosaic virus proteins this occurs at about 300 cycles.

For frequencies below these critical values the electro-optical properties of a colloid are characterized by the three functions $A(E_0, \omega)$, $B(E_0, \omega)$, and $\psi(E_0, \omega)$. It seems reasonable to expect that determinations of all three functions for a series of monodisperse colloids of various concentrations, with particles of various sizes, at different temperatures and pH values, may lead to a better understanding of the anomalous Kerr effect, than has heretofore been possible. It is obvious that, for a given field intensity, it is impossible to determine all three quantities from one single compensator reading. Since measurements with a compensator can be made, even if the optical shift is not steady, all previous observers have interpreted their data on the erroneous assumption that an alternating field always creates a steady optical shift. This has led to a series of wrong conclusions and it becomes necessary to reexamine the experimental procedures.

VISUAL MEASUREMENTS OF ALTERNATING BIREFRINGENCE

In the conventional optical system for measuring electro-optical effects the light passes successively through a polarizer, the Kerr cell, and an analyzer. If the Nicols are crossed and at 45° to the field direction, the intensity of the transmitted light is $I=I_0 \sin^2 \frac{1}{2}\varphi$, where I_0 is the transmitted intensity for parallel Nicols when no field is acting in the cell. If the optical shift is given by Eq. (3) we obtain

$$I=I_0 \sin^2 [\tfrac{1}{2}A+\tfrac{1}{2}B \cos (2\omega t-\psi)]. \quad (4)$$

For compensator measurements an additional adjustable optical shift φ_0 is introduced by the insertion of a quartz wedge between Kerr cell and analyzer. In this case

$$I=I_0 \sin^2 [\tfrac{1}{2}\varphi_0+\tfrac{1}{2}A+\tfrac{1}{2}B \cos (2\omega t-\psi)]. \quad (5)$$

For a Babinet compensator $\varphi_0=kx$ is proportional to the displacement x of the wedge from its zero position and k is the calibration constant of the compensator. For steady birefringence ($B=0$) the wedge is displaced until $I=0$. This occurs when $A=-\varphi_0=-kx$. It will be noted that this simple method could be modified so as to furnish A, B, and ψ by using stroboscopic illumination of frequency 2ω and adjustable phase angle. Unfortunately, this procedure is lacking in accuracy for the study of the anomalous Kerr effect, because in our solutions B is a

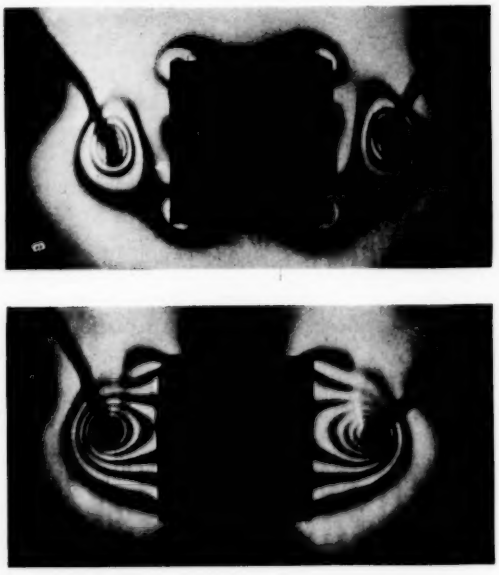

FIG. 2. Electro-optical field photographs of electric field between parallel wires. A cylinder of square cross section is placed between the electrodes. In the upper figure the cylinder is an insulator, in the lower figure it is made of nickel.

small fraction of A, except for fields of low frequencies.

In visual compensator observations one records the average light intensity, i.e., the time average of I over the period T of the electric field. If the light source is steady, one finds

$$I_{av}=\frac{1}{T}\int_0^T I dt=\tfrac{1}{2}I_0[1-J_0(B)\cos(kx+A)]. \quad (6)$$

J_0 is the Bessel function of zero order. For small values of B $J_0(B)$ approaches 1; it is an oscillating function with decreasing amplitude and with zeros for $B=2.40$; 5.52; $8.65\cdots$. The amplitude B of the alternating part of the optical shift is small for weak field intensities and is always small for fields of high frequencies. When B is small, it follows from Eq. (6) that the interference lines of the compensator remain visible, although they do not correspond to complete extinction. The intensity minima occur for $kx+A=2\pi n$, and the measurements furnish therefore the magnitude and also the sign of the steady part A of the optical shift. For strong low frequency fields, however, B can assume large values, and hence $J_0(B)$ becomes small, vanishes, and reverses its sign. Consequently, with increasing field intensity the fringes gradually become blurred and disappear when $B=2.40$. For stronger fields the fringes reappear again gradually without becoming sharp. Since $J_0(B)$ is now negative, the minima correspond now to $kx+A=(2n+1)\pi$ and they appear to have undergone a sudden shift. Errera, Overbeck, and Sack[3] and also Lauffer[3] have reported a gradual blurring of the interference lines, but they ascribe it to inhomogeneous field distribution, conduction, and heating in the Kerr cell. Our observations agree with the above explanation, because the lines reappear again in a shifted position after they have vanished.

Compensator measurements furnish the steady part A of the optical shift, but the determination becomes inaccurate when B becomes large. It should be noted that this determination is feasible only with a steady light source. An a.c. operated incandescent lamp furnishes illumination with an appreciable 120-cycle component. The resulting stroboscopic action is sufficient to influence the compensator measurements when the Kerr cell is operated with a low frequency. In particular, if the light source and the Kerr cell are operated from the same a.c. line, one finds that the fringes remain fairly sharp, but their positions depend on the phase angle between the light variations and the variations of the birefringence. It is impossible to interpret such data as recorded by Lauffer[3] for 60-cycle fields, without knowing the characteristics of the light source.

If the electro-optical effect is observed through crossed Nicols (without using a compensator), or through circular polarizers, the average transmitted light intensity is

$$I_{av}=\tfrac{1}{2}I_0[1-J_0(B)\cos A], \quad (7)$$

provided the light source is steady. With increasing field intensity A and B increase, and for monochromatic light the observed intensity passes through a series of minima. With white light one observes a sequence of colors. In a previous paper[6] it was shown how this fact can

[6] H. Mueller, J. Opt. Soc. Am. **31**, 286 (1941).

be used for the mapping of electric field distributions. Figure 2 presents two examples of field photographs obtained by this method. These pictures were obtained[7] by using circular polarizers and a 10,000 cycle field between the electrodes. For this frequency B is very small, $J_0(B)=1$, and the isochromatic lines are therefore considerably sharper than in the previously published[6] photographs, which were obtained for 60-cycle fields. When $B=0$, the distance between successive intensity minima corresponds to a change of the optical shift of 2π, and the extinction is complete. However, when B is large, the position of the isochromatic lines depends on the values of A and of B. This fact is illustrated by the curves in Fig. 3 which present the functions $I_w(A)$ for three typical cases: (a) when $B=0$, $I=\sin^2 \frac{1}{2}A$; (b) when $B=A$,

$$I=\tfrac{1}{2}[1-J_0(A)\cos A],$$

for steady illumination; and (c) for $B=A$ when the illumination is alternating with the same frequency as, and in phase with, the alternating optical shift. In the latter case

$$I=\tfrac{1}{2}[1-J_0(A)\cos A+J_1(A)\sin A],$$

where J_1 is the Bessel function of first order. Since the positions of the minima depend on two variables it is apparent that the isochromatic lines cannot serve for the determination of the electro-optical constants.

The above discussion shows that visual or photographic observations cannot distinguish between a steady and an alternating optical shift, because they record the average transmitted intensity. While, with the proper precautions, it is possible to obtain the magnitude and the sign of the steady part A of the optical shift from compensator measurements, the amplitude B and the phase angle ψ of the alternating part can be measured only from observations of the variations of the instantaneous value of the transmitted light intensity. This can best be accomplished by using a photoelectric method.

THEORY OF THE PHOTOELECTRIC METHOD

If the light transmitted by the optical system, consisting of Kerr cell and crossed Nicols, enters a photo-cell with linear characteristic we are justified in assuming that the photo-current i is given by an equation analogous to Eq. (4), namely,

$$i=i_0 \sin^2 [\tfrac{1}{2}A+\tfrac{1}{2}B\cos(2\omega t-\psi)], \qquad (8)$$

where i_0 is the photo-current for parallel Nicols when no field is applied to the Kerr cell. (This definition takes care of absorption losses and reflections.) A, B, and ψ can therefore be obtained from a study of the wave form of this current. To simplify the problem a steady monochromatic light source must be used for which i_0 is constant.

The photographs in Fig. 2 show that in our colloids we can readily produce steady shifts A which are five to seven times 2π. For bentonites with small particles the amplitude B is only slightly smaller than A in fields of 60 cycles. When A and B are both large, the wave form of the photo-current is very complicated, and small changes of the field intensity create large changes of the wave form. Figure 4 shows a series of $i(t)$ curves, calculated from Eq. (8) for the case $A=B$. Figure 5 shows the oscillograph records of the photo-current for a fine disperse bentonite sol in a.c. field. (These curves were obtained with a.c. illumination; note the phase shift between light variation and photo-current.) The observed curves show all the essential features of the calculated curves, but it would be extremely difficult to analyze the phenomenon from these curves.

To obtain a simple wave form of the photo-current it is necessary that A and B be smaller than $\frac{1}{2}\pi$. Now, according to Eq. (1), the magni-

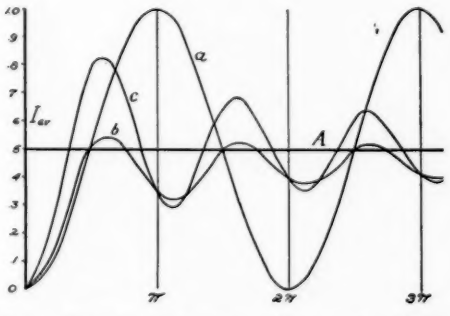

FIG. 3. Variation of the observable transmitted intensity as function of the steady birefringence for three different cases, see text.

[7] We are indebted to Mr. M. L. Ernst (B. S. Thesis, Massachusetts Institute of Technology, 1941) for the permission to reproduce these photographs.

tude of the optical shift can be reduced, without restricting the field intensity in the Kerr cell, by reducing the length of the Kerr cell. By choosing a long cell for measurements in weak fields, and a short cell for the study in strong fields, it is always possible to satisfy the condition $A \leq \frac{1}{2}\pi$. Furthermore, we find for most of the colloids which have been studied that in the entire acoustic frequency range B is considerably smaller than A. Certain exceptions will be pointed out later. Thus, if $A < \frac{1}{2}\pi$, B can be considered to be a small quantity. If terms in B^2 are neglected, Eq. (8) reduces to

$$i = i_0[\sin^2 \tfrac{1}{2}A + \tfrac{1}{2}B \sin A \cos(2\omega t - \psi)]. \quad (9)$$

The photo-current consists therefore of a steady current $i_1 = i_0 \sin^2 \frac{1}{2}A$ and an alternating current with a peak value $i_2 = \frac{1}{2}i_0 B \sin A$. The frequency of the alternating current is twice the frequency of the field applied to the Kerr cell. Its phase angle is identical with the phase angle of the optical shift. The d.c. and a.c. current can easily be separated by a simple network. In our experiments i_1 is measured with a galvanometer. The a.c. component is amplified. The value of i_2 is deduced from the output voltage of the amplifier and the phase angle is measured with a cathode-ray oscillograph. A and B are obtained from the relations

$$A = 2 \sin^{-1}(i_1/i_0)^{\frac{1}{2}}; \quad (10)$$

$$B = 2i_2/i_0 \cdot \sin A. \quad (11)$$

The approximation (9) is valid provided the coefficient of B^2 in the development of Eq. (8) into a power series is negligible. This coefficient has the value $(\frac{1}{4} - \frac{1}{2}\sin^2 \frac{1}{2}A)\cos^2(2\omega t - \psi)$. Hence, by adjusting the length of the Kerr cell in such a way that A does not differ appreciably from $\frac{1}{2}\pi$, one can minimize the influence of this correction

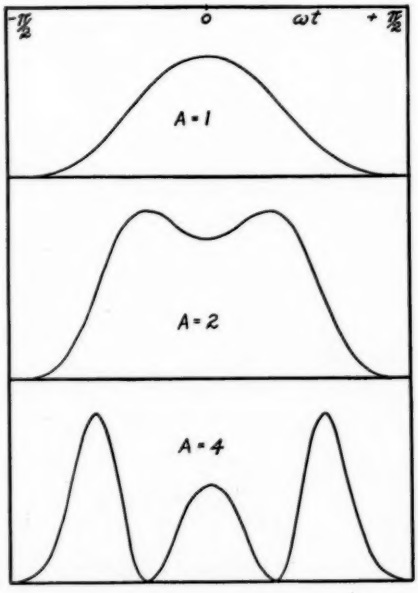

FIG. 4. Time variation of the instantaneous light intensity transmitted by a Kerr cell, when $A = B$, for various strengths of the alternating field.

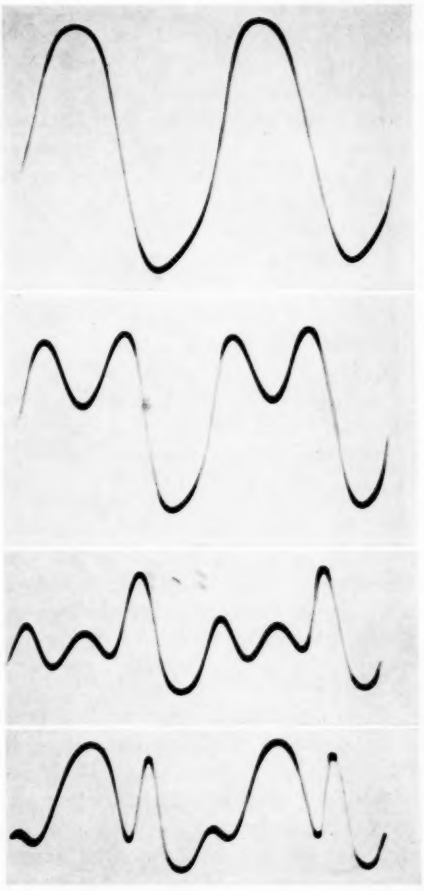

FIG. 5. Time variation of the instantaneous light intensity as recorded with a fine bentonite sol in fields of 60 cycle.

term. This procedure carries the further advantages of producing the largest possible value of i_2 and of eliminating higher harmonics in the alternating photo-current. The absence of higher harmonics is verified in all our measurements by means of a cathode-ray oscillograph.

For the determination of the phase angle ψ the horizontal deflection plates of the oscillograph are connected to the electrodes of the Kerr cell while the vertical plates are connected to the photo-current amplifier. The resulting pattern, representing $i_2 \cos(2\omega t - \psi)$ *versus* $E \cos \omega t$, is a Lissajous figure resembling a letter U when $\psi = 0$ and goes over into a figure ∞ when $\psi = 90°$. Figure 6 shows the photograph of the pattern for an intermediate value. ψ is determined from the position of the intersect along the vertical axis. In these measurements it is necessary, of course, to take into account the phase shifts introduced by the amplifier.

This photoelectric method furnishes reliable results when $B < \frac{1}{4}A$ and permits the determination of small B values of the order of magnitude $\pi/3000$. Its main deficiency lies in the fact that it leaves the signs of A, B, and of ψ undetermined. In the case of ψ this uncertainty is irrelevant, because it seems inconceivable that the phase could be leading. On the basis of the assumption that ψ always is a lag it is possible to determine the sign of i_2 and hence of $B \sin A$ from the Lissajous figure, because a reversal of i_2 causes the figure to be inverted (reflection on the horizontal axis). Thus, since the measurements are performed when $A \leq \pi/2$, the sign of the product AB can be determined. To arrive at the signs of A and of B, it is necessary to resort to compensator measurements, which, as we have shown, furnish the sign and magnitude of A. In our experimental procedure every photoelectric measurement is supplemented and checked by a compensator reading.

A modification of the photoelectric method is necessary when A and B are nearly of the same magnitude, or when $A < B$. The first case arises in finely dispersed bentonites for low frequency fields. This case can also be investigated with the stroboscopic compensator method. The second case is met with in concentrated solutions of bentonite and in the virus proteins, where the steady part A of the birefringence undergoes a reversal of sign. This reversal can be accomplished either with variation of the field intensity, or by changes of the field frequency, or by diluting the solution. At the reversal points, where $A = 0$, the photo-current i follows, in first approximation, the law $i = i_0(B^2/8)(1 + \cos 4\omega t)$. Near the reversal points the alternating photo-current is not sinusoidal. Observation of the wave form or of the Lissajous figure gives a very accurate determination of the reversal point.

To adapt the photoelectric method to these exceptional cases it is necessary to choose a cell length for which B is smaller than $\pi/8$, and to insert a quarter-wave plate between Kerr cell and analyzer. The steady part of the total optical shift is then $A^{\#} = A \pm \frac{1}{2}\pi$, and differs, in both cases, very little from $\frac{1}{2}\pi$. Hence Eqs. (10) and (11) can be used for the determination of $A^{\#}$ and B, and ψ is obtained from the Lissajous figure. The quarter-wave plate need not be exact, but its phase shift must be measured accurately.

THE EXPERIMENTAL METHOD

It follows from the preceding discussion that the experimental method must satisfy the following requirements: a. The length of Kerr cell is to be adjustable to meet the condition $A = \frac{1}{2}\pi$ for different field intensities. b. The optical system should permit a switching over from photoelectric to compensator measurements, because both

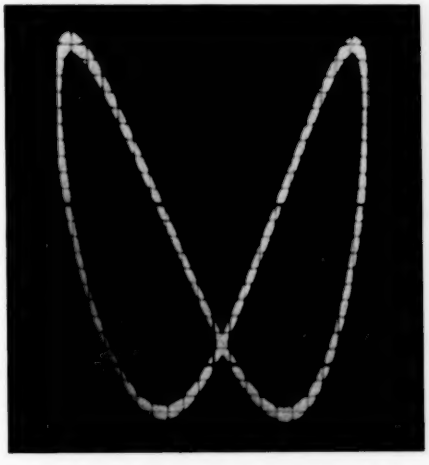

FIG. 6. Lissajous figure for the determination of the phase angle of the electro-optical effect.

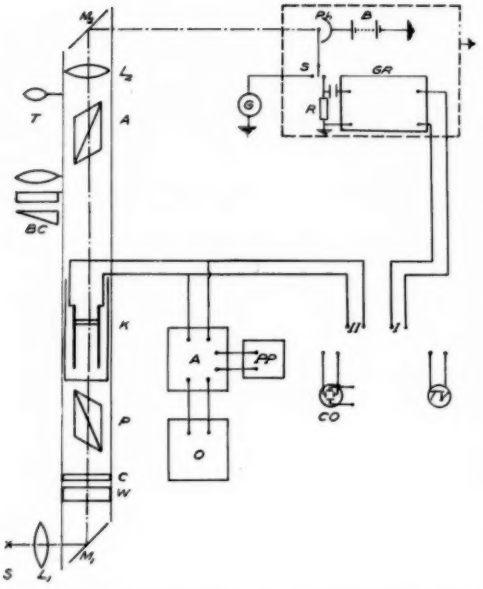

FIG. 7. Experimental arrangement. *O* oscillator, *A* amplifier with power pack *PP*, *K* Kerr cell, *S* source, *L* lenses, *M* mirrors, *C*, *W*, filters, *P*, *A* Nicols, *BC* compensator with telescope *T*, *Ph* photo-cell, *GR* amplifier, *G* galvanometer, *TV* tube voltmeter, *CO* cathode-ray oscillograph.

types of data are needed for the determination of magnitude and sign of the three quantities A, B, and ψ. Two additional requirements, namely, c. Temperature control of the Kerr cell, and d. Accurately sinusoidal wave form of the voltage applied to the Kerr cell, must be satisfied for the following reasons: The colloids are heated in the electric field because they are conductive. A temperature change alters the viscosity and hence the relaxation time. This effect in turn influences the values of B and of ψ. Very slight deviations from the sinusoidal wave form of the voltage give rise to a large error in the photo-electric measurements in fields of high frequencies. For these fields the alternating part of the photo-current is small. Due to incomplete filtering in the power pack the output of most commercial audio-amplifiers is modulated with 120 cycles. Even though this modulation may amount to less than 1 percent, it gives rise to large alternating photo-current, because the orientation of the particles responds easily to this low frequency. This difficulty is avoided by introducing additional filters. As a precautionary measure the wave form of the voltage on the Kerr cell and of the photo-current is to be checked periodically with the oscillograph.

Our experimental arrangement, which meets the above requirements, is shown schematically in Fig. 7. The source of constant frequencies is a beat frequency oscillator, covering the range from 50 cycles to 15 kc. Its output is amplified by the audio-amplifier A. To secure a good wave form it was found necessary to shield the powerpack PP from the amplifier. The output of the latter is 20 watts, the maximum voltage 150 volts; for higher voltages the wave form is unsatisfactory. The Kerr cell K is a Pyrex tube of 2.2-cm inner diameter and 13 cm in length. It is mounted vertically in a temperature bath. A strain free Pyrex window forms the lower end of the cell. The electrodes are two plates of nickel, 1.4 cm wide and from 1 to 6 cm in length. They are held parallel and 1 cm apart by a short fiber tubing which fits tightly into the upper part of the glass tube. The electrodes touch the lower window. A strain free glass plate is clamped between the electrodes and is in contact with the free surface of the colloid. This plate is necessary to prevent refraction and reduce reflection at the free surface of the solution. The length of the Kerr cell is adjusted by varying the amount of colloid and by moving the glass plate. Since the electrodes touch both windows and since the solution is a conductor, no edge corrections for the Kerr condenser are needed. The electric field in the central portion between the electrodes is found to be uniform. The illumination is supplied by a 500-watt incandescent lamp. Normally it is operated on d.c., but occasionally it is connected to the a.c. line for preliminary investigations. A system of lenses, mirrors, and stops gives a parallel light beam, which passes through water filter W, color filter C, polarizer P, Kerr cell K, and analyzer A. Analyzer and polarizer are Nicol prisms. Lens L_2 concentrates the transmitted light over an Al-surfaced mirror M_2 into the photo-cell. L_2 and M_2 can be swung out of the path of the beam to permit measurements with the compensator BC which is observed through the telescope T. We use a Babinet compensator which reads the optical shifts to an accuracy of $2\pi/150$. To prevent pick-up from the power amplifier A, it is necessary to shield the photo-cell

and its amplifier *GR* extremely carefully. The latter is operated on batteries. The direct part of the photo-current is measured with a galvanometer *G*.

In performing the measurements the voltage on the Kerr cell is measured with an electron tube voltmeter and its wave form is observed with the cathode-ray oscillograph. Next, these two instruments are connected successively to the photo-cell amplifier for the measurement and wave form control of the alternating photo-current. The phase angle ψ is found by connecting the vertical plates of the oscillator to the photo-cell amplifier while the horizontal plates are connected to the electrodes of the Kerr cell. The galvanometer reading gives the direct part of the photo-current and determines A. This determination is finally checked by means of the compensator, which furnishes the sign of A.

This equipment has proved to be adequate for the study of the anomalous electro-optical effects in bentonite colloids, for frequencies above 50 cycles per sec. By using a radiofrequency oscillator and an r-f amplifier in place of the beat-frequency oscillator and the audio-amplifier the measurements have been extended to the radio range up to 10 megacycles. These investigations are of limited interest because it is found that from 10 kc to 10 mc the birefringence is steady and the effect is independent of frequency. For bentonites with particles larger than 0.2μ and for the mosaic virus proteins it would be desirable to extend the frequency range to below 50 cycles. This has not yet been attempted, partly because in colloids with large particles the optical problem becomes more complicated. They show a large Tyndall effect and they become dichroic under the influence of the electric field. Both effects introduce considerable errors in our photoelectric determinations.

ACKNOWLEDGMENTS

We are indebted to Mr. O. H. Fulton for help in the design and construction of the electrical equipment, to Mr. M. L. Ernst for the pictures shown in Fig. 2, and to Mr. G. J. Yevick for assistance in the preparation of the manuscript.

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The Fatigue Effect in Luminescent Materials

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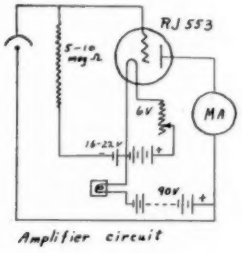
(Received February 23, 1942)

Many luminescent substances show a fatigue effect or loss of efficiency with continued exposure to ultraviolet light. Measurements made on several inorganic phosphors, organic substances such as anthracene and on fluorescent canary glass, showed that the losses increased with time and intensity of irradiation. The phenomenon can be demonstrated with liquids as well as with solid crystalline material. Equilibrium conditions were attained in about ten minutes. Both short ultraviolet radiations at 2537A and longer radiations at 3650A were used. The recovery from fatigue was demonstrated with a number of substances. Several samples of luminescent sulfides were exceptions in that they did not show the fatigue phenomenon. Decreases in light output can also be demonstrated with cathode-ray excitation.

THE term "fatigue effect" is used to describe the temporary loss of efficiency in a luminescent material with continued exposure to ultraviolet radiations. This is quite different from the phosphorescent afterglow of certain irradiated luminophores where visible light is given off with diminishing intensity until the substance is completely dark. Fatigue takes place during continued exposure to a constant source of ultraviolet radiations while phosphorescence decreases after the exciting source of ultraviolet is discontinued. Phosphorescence may be explained by the temporary trapping of electrons in metastable states or energy pits from which they are gradu-

ally released by thermal agitation of the lattice molecules. The cause of the fatigue effect in luminescent materials is probably similar to the fatigue effect in photo-elements where the phenomenon is due to the displacement of the active emission centers from their normal positions. When ionized by the loss of valence electrons the atoms may migrate or be displaced slightly in the crystal structure and thus be incapable of emitting luminescence with their initial efficiency.

The decrease in sensitivity of selenium photo-elements during exposure to constant sources of light has been described by Lange[1] and he showed that the fatigue was much greater when the photo-element was exposed to intense sources of illumination than when exposed to weak sources of light. Equilibrium values were reached in about 10 minutes. Bergman[2] observed a pronounced fatigue in selenium photo-elements when exposed to x-rays. Here also the effect was most pronounced with the highest intensities of x-rays. The fatigue phenomenon has been known for a long time as applied to cathode-ray excitation. In 1879 Crookes[3] found that after glass had been fluorescing for some time under cathode-ray bombardment it seemed to get tired and showed a pronounced reduction in brightness. This phenomenon is readily demonstrated with a Crookes' tube having a Maltese cross to form a shadow at the end of the tube. If the cross is removed after the discharge has continued for some time, the pattern of the cross is still to be seen on the glass, but it will now be brighter instead of darker than the surrounding field. Because the portions shielded by the cross are not tired from continued exposure, they respond more vigorously to the cathode-ray bombardment than those portions that were exposed for extended periods of time.



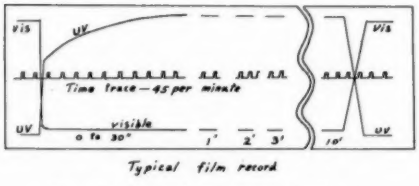


FIG. 1. (Above.) Amplifier circuit.

FIG. 2. (Below.) Typical film record.

This paper describes a number of experiments that were performed to investigate the fatigue effect in certain fluorescent substances when irradiated with ultraviolet light.

METHOD AND APPARATUS

To get intense short wave ultraviolet radiations to irradiate the fluorescent materials, it became necessary to place the substances inside a low pressure mercury vapor lamp or to paint the powdered material on the outside of such a lamp having a quartz envelope. At least one section of the envelope must be of clear transparent quartz tubing to obtain a measure of the ultraviolet generated inside the tube. A one-half inch diameter quartz mercury lamp, one end clear and the other end coated with a zinc silicate phosphor powder was used for some of the experiments.

Time is another factor entering into such measurements, for the effects may be over before the ordinary meters could register any difference. A multi-element high speed oscillograph was used to get simultaneous measurements of the visible and ultraviolet light from the lamp together with a suitable time scale. With this instrument, time intervals as short as 0.005 minute could be read. Records were obtained on a film 4″×12″ and time intervals of 0 to 30 sec., 1, 2, 3, 5, 7, 10 minutes were generally chosen. The camera was allowed to run for 30 sec., then it was stopped and run intermittently for only a few seconds at the other time intervals.

A thorium ultraviolet photo-cell was used to pick up the 2537A radiation that came through the clear quartz section while a caesium photo-cell registered the visible light. Two independent single tube d.c. amplifiers were used to amplify

[1] B. Lange, *Photoelements and Their Applications* (Reinhold Publishing Corporation, 1938), p. 164.
[2] Reference 1, p. 130.
[3] Wm. Crookes, Phil. Trans., Part 2 (1879), p. 645.

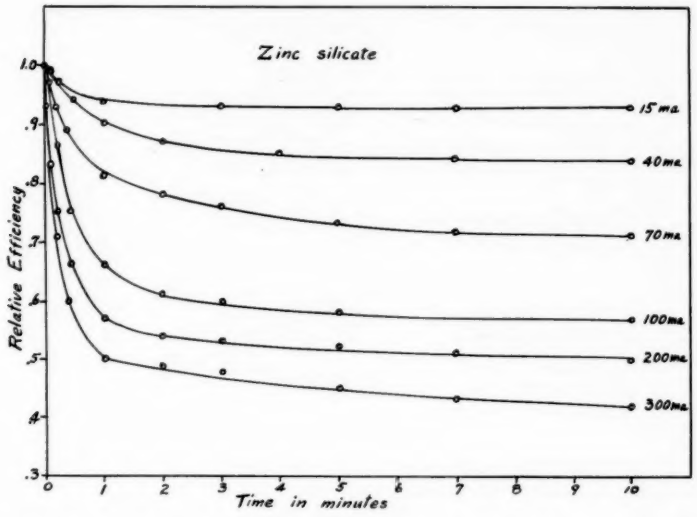


FIG. 3. Fatigue of zinc silicate coated on the inside of a ½-inch lamp showing the effect of current density.

the photo-currents sufficiently to activate the oscillograph galvanometers. RJ 553 tubes were selected for the amplifiers, the circuit of which is shown in Fig. 1. With grid leaks of 2 to 10 megohms, a plate current of 10 or 15 ma was obtained which was sufficient to give nearly full scale deflections across the film. All amplifier and lamp voltages were d.c. to eliminate possible 60-cycle fluctuations. Figure 2 shows the type of records obtained. The traces from the two photo-cells were started at opposite sides of the film so there would be no danger of the two traces coalescing or touching each other. A time trace was set near the middle of the film and was obtained by a make-break contact on the teeth of a worm gear used to drive the camera. The time interval was always 45 per minute because of using a synchronous motor to drive the reduction gear. For normal work the time intervals were about 3.4 mm apart, while for higher speeds, obtained by changing belt pulleys, separations of 12.0 mm were obtained for each time interval.

Corrections were applied to the recorded data to allow for the visible light from the mercury discharge. Two records were made for each tube current, one for the light from the fluorescent material plus the visible light from the mercury discharge transmitted through the coating and the other with the light from the mercury discharge coming through the clear quartz tube. On each record both the ultraviolet energy as received by the thorium photo-cell and the visible light as received by the cesium photo-cell were recorded. A waiting interval of at least 15 minutes was allowed between successive runs to permit the powders to regain their initial values. To get an absolute value for the correction to be applied, a photronic cell was used to evaluate the light both from the fluorescent section and from the clear section at the end of ten minutes operation. Corrections varied with tube currents, being greatest with large tube currents and also with time of burning, being greater at the beginning of a run than at equilibrium.

To determine the correction factor, one must also know the transmission of the coating material for visible light. The transmission of the coating was measured on a similarly coated piece of tubing that had been split along the axis so that a single surface could be measured. Measurements were made by passing the light from a projection lamp through a lens, a screen with a narrow slit, then through the coated tubing and allowing the light to shine on a photronic cell. The transmission for the particular piece of zinc silicate coated tubing was about 50 percent.

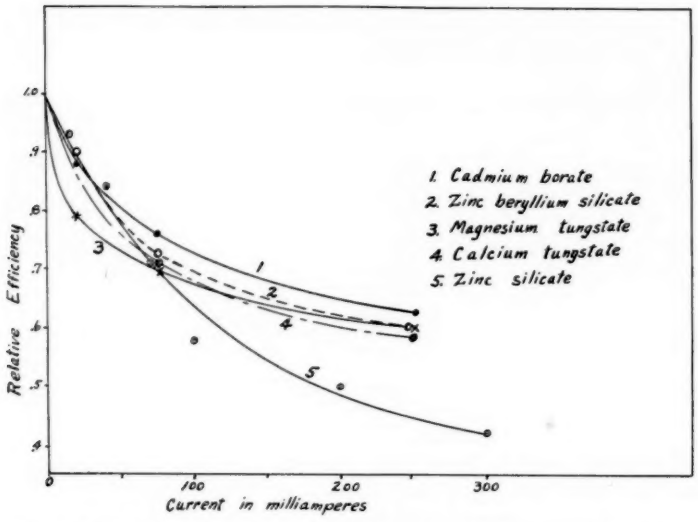


FIG. 4. Equilibrium values of several phosphors for different current densities.

OBSERVED RESULTS

Various currents were passed through the lamp such as 15, 40, 70, 100, 200, and 300 ma. After applying the proper corrections to allow for the visible light from the mercury discharge, one can plot a curve for each tube current showing the relationship between relative efficiency and time. A series of such curves for zinc silicate is shown in Fig. 3. The decrease in efficiency is very pronounced for the larger tube currents and is most rapid at the start of irradiation.

Preliminary measurements on a quartz tube coated externally with various phosphors showed that all these phosphors exhibited a measurable fatigue effect. A new lamp was made with tubular sections of glass 1.4 cm I.D. and 7.5 cm long coated internally with various phosphors. These sections were placed inside a closely fitting outer glass tube to which was attached a quartz section of the same size as the coated sections, so that a direct measure of the ultraviolet from the discharge could be had. Duplicate sections were coated and then cut lengthwise so that transmission measurements could be made of the various coatings for white light. Zinc beryllium silicate, calcium tungstate, and magnesium tungstate were of such opacity as to transmit about 50 percent of incident white light, while the cadmium borate surface transmitted about 40 percent. These values are only approximate as they entered only as a correction factor.

The equilibrium values, i.e., the values at 10 minutes of all 5 phosphors are plotted in Fig. 4, and show that there is an increased loss of efficiency with increased current density or with increased intensity of ultraviolet radiations. Zinc silicate exhibits the greatest fatigue effect.

To investigate the effect of temperature on the fatigue phenomenon the zinc silicate lamp was used with currents of 250 ma while it was immersed in a glass trough filled with water at various temperatures. Temperatures of 16°C, 27°C, and 60°C were used in the water bath. No corrections were made for the visible light for relative values only were desired. The data show that the fatigue is more rapid with high temperatures than with low temperatures, practically all of the 50 percent fatigue loss occurred in the first two seconds of operation at 60°C ambient temperature. Eventually all fatigue curves reach the same steady state value and the phosphor is then independent of temperature. The air cooled lamp shows a slower rate of fatigue than the water cooled lamps.

A sample of phosphorescent white willemite mineral was available so a small piece was pulverized and then dusted onto a glass plate that had been coated with a thin film of potassium

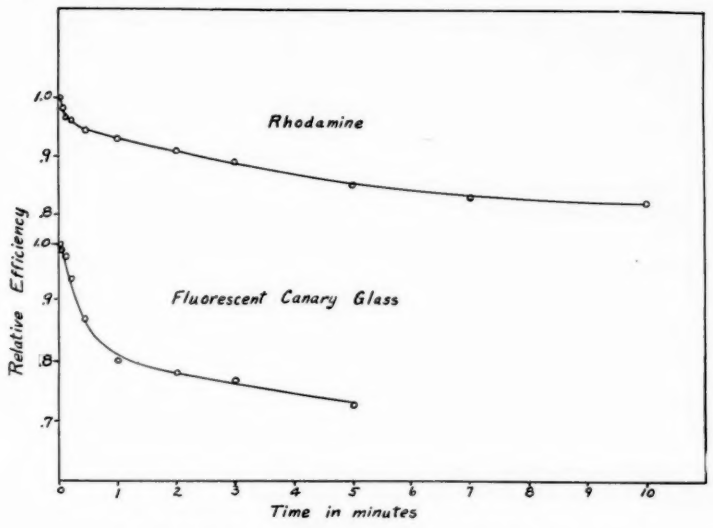


FIG. 5. Fatigue of rhodamine and fluorescent canary glass.

silicate. This was irradiated with a small quartz mercury lamp, light being measured with a cesium photo-cell, B battery, and microammeter. The fatigue loss was about the same as from a plate coated with synthetic zinc silicate that gave but little phosphorescence.

OTHER LUMINESCENT MATERIALS

An attempt was made to verify the above described fatigue effect in phosphors with other luminescent materials. An organic dye such as rhodamine should be quite different physically from the inorganic phosphors, and when excited by 3650A radiation a new set of conditions were established. Rhodamine paint was flowed over a glass plate and allowed to dry in air. When this plate was irradiated with a constant source of 3650A radiation (a reflector type H4 lamp and Corning No. 588 filter), the intensity of fluorescent light gradually diminished with time of irradiation. Also when intermittently exposed and shielded from the source the readings would repeat, always higher after resting and lower after exposure. The reduction in fluorescence was greatest with high intensity of ultraviolet. A quartz water cell 1 cm thick was placed between the lamp and the fluorescent plate to screen out infra-red radiations. Readings were made with a cesium photo-cell connected to a 90-v battery and microammeter. A K_2 gelatine filter in front of the photo-cell screened off any 3650A transmitted radiation. With the apparatus as arranged in the experiment a fatigue of approximately 8 percent was observed.

With the same apparatus a fatigue effect of 22 percent was obtained with a sample of uranium glass (fluorescent canary glass) 2 inches square, $\frac{1}{4}$ inch thick. To obtain better data with the rhodamine plate and canary glass the samples were measured with the aid of the oscillograph, cesium photo-cell, and amplifier. A 400-watt quartz lamp operated on d.c. with an input of about 150 watts caused the lamp to be very steady. The data are recorded in Fig. 5 and show a very pronounced fatigue effect.

Experiments were performed with anthracene, both in the dry powder form and in a liquid solution of ethyl alcohol. Measurements were made with the oscillograph, cesium photo-cell and amplifier, and the 400-watt quartz lamp. The data are recorded at the top of Fig. 6, and show that both the dry powder and the solution have a noticeable fatigue effect, that of the liquid solution being more pronounced. The solution was in a glass cell 1 cm thick. Fluorescein was dissolved both in ethyl and in methyl alcohol and tested for fatigue of fluorescence. From the lower

curves of Fig. 6 it is seen that the methyl alcohol solution shows the greater fatigue.

Two different samples of synthetic fluorescent sulfides were obtained, both showing a strong phosphorescent effect. One was zinc sulfide giving yellow luminescence, the other was zinc-cadmium sulfide giving an orange luminescence. When observed with a photronic cell or cesium cell, and irradiated with 3650A radiation from a reflector H4 lamp, there was no measurable fatigue effect. With continued exposure there was no falling off of emitted light, nor was there a difference between the exposed and rested conditions. To improve upon the method of measurement, the oscillograph was used, but in both cases there was no measurable fatigue effect. Sulfide phosphors are the only samples of fluorescent material that have been measured that do not show a fatigue effect.

RECOVERY FROM FATIGUE

If a substance shows a "fatigue" or loss of activity upon irradiation then unless it be a permanent chemical or physical change, the material should recuperate or recover from the fatigue process after a suitable rest period in the dark. Several measurements were made on the sample of fluorescent canary glass and on zinc silicate powder. In the first test light from the 400-watt quartz lamp was passed through a water cell, then through a corex red purple glass filter and allowed to fall upon the fluorescent glass plate. Visible light was measured with a Cs photo-cell and amplifier. The sample was irradiated for 1-min. time intervals with 3650A radiation with various rest periods between. The recovery was the difference between the reading just before and just after the rest period where the sample was screened from the lamp with an opaque screen. In the second run the sample was irradiated for 1 min., rested for the various time intervals, another reading quickly made, and the sample further screened off until a total of 4 minutes rest period had elapsed when the sample was again irradiated for 1 min. This practically duplicates the first set of readings. Both sets of data are recorded in Fig. 7. Measurements were also made on the recovery of zinc silicate using 2537A radiation from a small quartz mercury lamp. The first run was made with 90-sec. irradiation periods and various rest periods and the second run with two minute periods of irradiation and various rest periods between. Both these curves are identical as seen in lower part of Fig. 7.

FATIGUE OF ZINC SILICATE WITH CATHODE RAYS

A special discharge tube was made to test the fatigue effect with cathode rays. It consisted of a

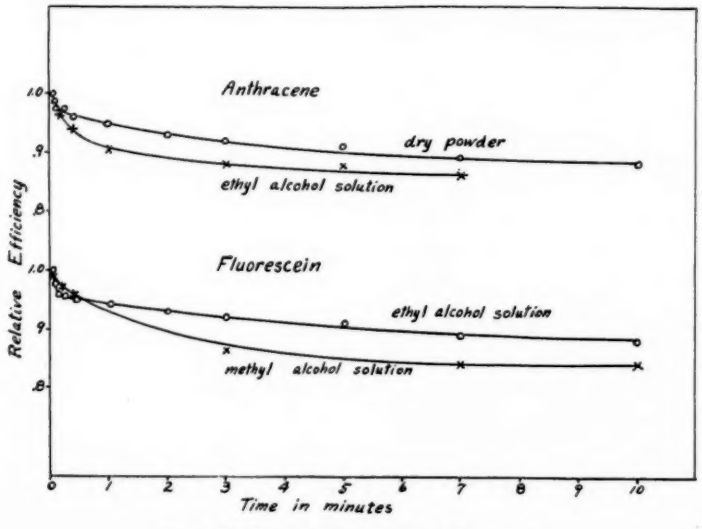


FIG. 6. Fatigue of anthracene and fluorescein.

7-inch diameter glass bulb having two arms diametrically opposite each other. In one arm was a 2-inch diameter spun metal cup upon which the fluorescent material was deposited. The other arm contained the electron source. Rectified current from a 3000-volt transformer supplied energy to the cathode stream. The anode was coated with a suspension of zinc silicate in a thin potassium silicate binder, and also with coating formed by the settling of the powder out of a water solution. A noticeable reduction in spot intensity was always observable after the electron bombardment had continued for a short time, indicating that the fatigue phenomenon was present. Measurements made with a photronic cell showed that the fluorescent light decreased about 30 percent during the first 10 to 15 seconds operation.

As a check on this fatigue phenomenon with cathode rays, observations were made on a DuMont oscilloscope having a green fluorescent screen. A well focused beam was caused to vibrate horizontally and then intermittently caused to expand vertically so as to fill up a solid rectangle of light. An increase of total light of about 30 percent was recorded with the photronic cell connected to a high sensitivity galvanometer. Then the spot was focused to a small round focal spot and intermittently caused to expand to a line about an inch long. Here again the total light increased 30 to 40 percent.

The reduction of light from a concentrated spot might be due to accumulated electrical charges on the phosphor particles repelling the incident electrons, the extended areas not being charged to as great an extent because the charges can leak off better from an extended area. In the experimental tube such charging up should not be an important factor since the thin layer of powder was placed directly on the metal anode. Local heating on the incident powder surface may cause reduced output, but the heat capacity of the metal anode of the experimental tube should keep the powder relatively cool. A better explanation of high output from the extended light source on the oscilloscope screen is that the powder is exposed to radiation for only a short period of time and recovers between successive traverses of the cathode beam.

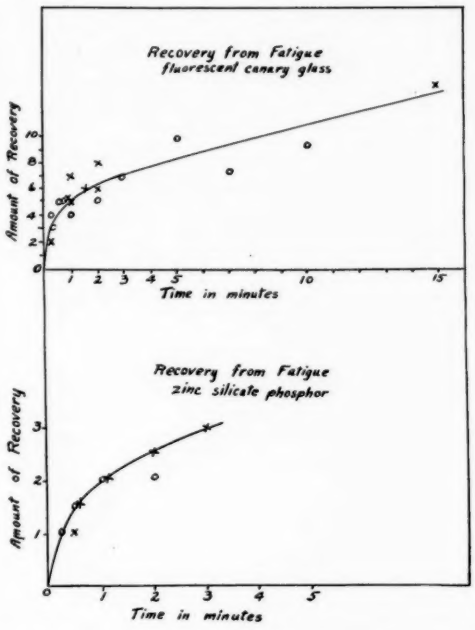


FIG. 7. Recovery from fatigue of fluorescent canary glass and of zinc silicate.

Note on the Transmission of Photographic Layers in the Ultraviolet

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(Received April 8, 1942)

CONTACT printing density has been measured in the past by several workers.[1-6] In the course of an investigation of this subject in these laboratories, the author was confronted with a disturbing anomaly. Our results suggested that ordinary photographic deposits must have a higher transmission in some portion of the extra-visible spectrum than at visible wave-lengths. This conclusion was formed somewhat hesitantly because many authorities considered it a basic fact that the transmission continuously decreased at the shorter wave-lengths.

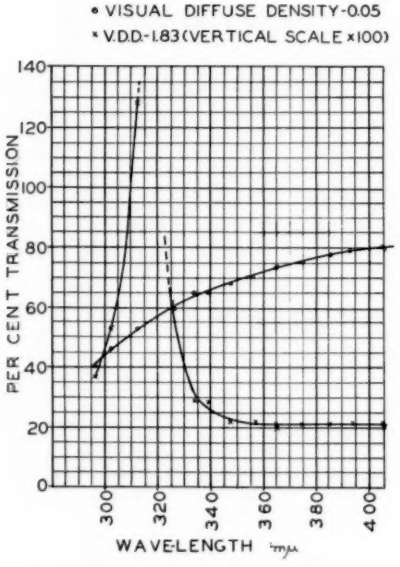

FIG. 1. Ultraviolet transmission of two photographic layers of different density levels.

Through the courtesy of W. E. Forsythe and B. T. Barnes, of the General Electric Company, spectral transmission curves were made in the ultraviolet region using their large quartz double monochromator for two unstained developed silver images. Their curves are shown in Fig. 1. The denser sample had a visual diffuse density (V.D.D.) of 1.83, the thinner, a density of 0.05 (fog density).

The thin sample appears to behave as would be expected from the supposition that the ultraviolet transmission is lower than the transmission in the visible region. However, it must be remembered that the portion of the total density contributed by the silver image is very small in this case. Most of the ultraviolet density is probably due to the gelatin.

The denser sample shows a very abrupt rise and very high transmission in a narrow band at 320 mμ. Elsewhere, the behavior is quite normal.

This enormous increase in transmission over the region indicated explains very nicely many results obtained in the past by other workers. For example, if in density measurements any part of the optical system absorbs flux of wave-lengths shorter than 330 or 340 mμ, the results should agree with visual estimates. If, on the other hand, all of the elements are such as to transmit some flux between 300 and 330 mμ, the

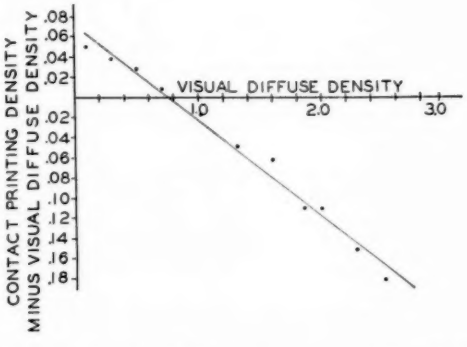

FIG. 2. Density difference between contact printing densities and visual densities as a function of V.D.C. (contact printing material sensitive to ultraviolet).

[1] F. C. Toy, "The standardization of photographic density measurements," Phot. J. **49**, 164 (1925).
[2] F. Renwick, "Visual and printing density measurements," Phot. J. **49**, 293 (1925).
[3] W. B. Ferguson, "Standardization of measurements of photographic density," Phot. J. **50**, 294 (1926).
[4] C. Tuttle, "Densitometry and photographic printing. Illumination of the negative and its effect upon density," J. Opt. Soc. Am. **24**, 272 (1934).
[5] A. Koerner and C. Tuttle, "Experimental determination of photographic density," J. Opt. Soc. Am. **27**, 241 (1937).
[6] J. G. Frayne, "Measurement of photographic printing density," J. S. M. P. E. **36**, 622 (1941).

effect will be to render low C.P.D. slightly higher than V.D.D. and high C.P.D. lower than V.D.D. as in Fig. 2.* Figure 2 is a plot of experimentally determined values (see reference 7). Although the light source was a tungsten filament lamp at 2750°K and the light was passed through two plain glass elements (thus limiting the relative amount of ultraviolet energy incident on the film specimen), the 320 effect was so great that for a sample whose V.D.D. was 2.8, the C.P.D. was of the order of 0.3 lower. This density difference corresponds to a transmission ratio of 2 : 1.

The fact that the same general C.P.D. *vs.* V.D.D. relationship exists for a wide variety of photographic layers indicates that the 320 mμ effect is not peculiar to the samples measured by Messrs. Forsythe and Barnes.

Literature references to the reflectivity of silver and the transmission of silver foil have recently come to the writer's attention.[8] Curves are given for independent determinations of the reflectivity of silver by different workers. Their average is shown in Fig. 3, and in every case the sharp decline in reflectivity occurs in the region of 320 mμ. These results obviously parallel the high density curve of Forsythe and Barnes.

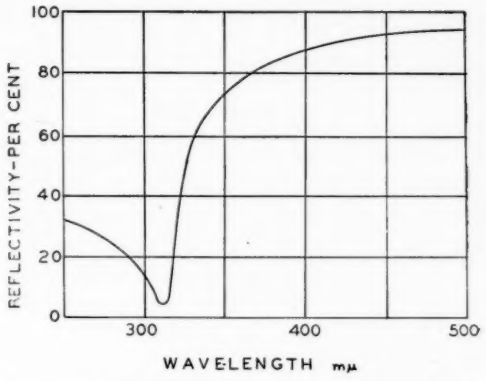

FIG. 3. Reflectivity of metallic silver surfaces in the ultraviolet region.

Because of the importance of contact printing density in the photographic industry, it is hoped that these findings will contribute toward a satisfactory solution to the problem of density standardization which confronts the A. S. A. Committee.

* Assuming the receiver to have some sensitivity at 320 mμ.

[7] M. H. Sweet, "Photographic density determined by the contact printing method," J. P. S. A. **7**, 4, 126 (1941).

[8] Lawrence Addiks, editor, *Silver in Industry*, p. 31 and bibliography (Reinhold Publishing Co., New York, 1940).

The Effect of Gradual Light Absorption in Photographic Exposure*

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(Received April 2, 1942)

THE effect of absorption in a thick emulsion coating upon the resultant photographic density and contrast (gamma) has been treated exhaustively in my similarly entitled paper of 1939[1] for the special case of an elementary exposure law[2] based on the quantum theory and the one- or two-quanta hypothesis, and for an emulsion of an exponential size-frequency distribution of its grains.

The purpose of the present paper is to treat this problem in its full generality, that is to say, without specifying at all the form of the elementary exposure law.

Consider a uniform layer of emulsion of thickness a, contained between two parallel planes or faces. Let k, a constant, be its absorption coefficient per unit thickness. Then, if E be the net exposure (incident minus reflected) at the top face, the exposure at a depth x is

$$E_x = Ee^{-kx}.$$

Let the photographic density produced by this exposure in a layer of infinitesimal thickness dx be

$$(1/a)f(E_x)dx,$$

where f may be any function whatever of its argument, only continuous and differentiable. (It is the form of the function f which has been alluded to above as the elementary exposure law.)

Then the resultant photographic density of the whole layer due to an exposure E at the top face is

$$D(E) = \frac{1}{a}\int_0^a f(E_x)dx = \frac{1}{a}\int_0^a f(Ee^{-kx})dx. \quad (1)$$

In the ideal case of no absorption ($k=0$), (1) reduces to $D_0(E)=f(E)$. Also, for $E=\infty$, the limiting density $D_m=f(\infty)$, identical with the limiting density for the ideal case. The transparency (or net transmittance) of the whole layer is

$$T = e^{-ka}. \quad (2)$$

What is called the sensitometric or the H and D (Hurter and Driffield) curve is the plot of D against Log E (base 10). The gradient or slope of this curve, at any of its points, is

$$g(E) = (E/M)D'(E), \quad (3)$$

where $M=\text{Log } e=0.4343$; the plot of g against Log E is called the slope-curve, and its maximum ordinate, attained at the inflection point $\bar{E}$ of the H and D curve, is called contrast, or gamma (γ).

Returning to Eq. (1), we may view it in a twofold way:

Given the form of the function f, find $D(E)$ or the corresponding slope $g(E)$ for any E or, inversely, given D for all E, find $f(E)$.

The first or direct problem is virtually solved by (1) itself which reduces it to a quadrature, an integration over x. Such an integral, however, is (even for the simplest form of f worth contemplating) not reducible to known functions. It will, therefore, be interesting to show that the corresponding slope $g(E)$ can be found explicitly at once.

The second or inverse problem amounts to solving a *sui generis* integral equation,[3]

$$\frac{1}{a}\int_0^a f(Ee^{-kx})dx = D(E),$$

with $D(E)$ as the given and f as the unknown function. This problem is actually, to the student of photography, of greater importance than the direct one. For what is accessible to easy and accurate observation and measurement is the density D for a thick emulsion coating, and the "elementary law" has, phenomenologically, to be derived from such measurements.

* Communication No. 850 from the Kodak Research Laboratories.

[1] L. Silberstein, J. Opt. Soc. Am. **29**, 67–76 (1939).

[2] I.e., the relation between photographic density and exposure in an emulsion layer of infinitesimal thickness.

[3] The usually so-called and widely known "integral equations" are of an essentially different form. Our equation will be seen presently to be much easier to solve.

Now, it has turned out that both problems can be solved in a surprisingly simple way. (The solution of the first has already been given in the 1939 paper for the sake of a special application, but to facilitate reference, its brief derivation is included here.)

In fact, the derivative of (1) with respect to E is

$$D'(E)=\frac{1}{a}\int_0^a f'(Ee^{-kx})e^{-kx}dx. \tag{4}$$

Multiply both sides by E and put $Ee^{-kx}=u$. Then $Ee^{-kx}dx=-du/k$ and

$$ED'(E)=-\frac{1}{ka}\int_E^{TE}\frac{df}{du}du,$$

that is to say,

$$ED'(E)=(1/ka)\{f(E)-f(TE)\}. \tag{5}$$

The right-hand member contains only the *terminal* values of the function f, *viz.*, those at the top and at the bottom of the whole emulsion layer.

In terms of the gradient g, this remarkable relation becomes, by (3) and since

$$\begin{aligned} Mka &= -M\log T=-\mathrm{Log}\ T,\\ g(E) &= -(1/\mathrm{Log}\ T)\{f(E)-f(TE)\}, \end{aligned} \tag{6}$$

which reads: the gradient of the actual H and D curve at any exposure E is proportional to the difference of the ideal (absorption-less) densities at this exposure and at the lower exposure TE. If, for example, $T=\frac{1}{2}$, then

$$g(E)=\{f(E)-f(\tfrac{1}{2}E)\}/\mathrm{Log}\ 2.$$

The proportionality factor in (6) is always positive and if, as we may readily assume, f is an always increasing function, $g(E)$ is always positive and D an always increasing function of the exposure.

The inflection point $\bar{E}$ of the D, Log E curve is determined by $g'(E)=0$ and thus by the equation

$$f'(\bar{E})=Tf'(T\bar{E}). \tag{7}$$

If $\bar{E}$ be the proper root of this equation, then $\gamma=g(\bar{E})$, i.e., by (6),

$$\gamma=-\frac{1}{\mathrm{Log}\ T}\{f(\bar{E})-f(T\bar{E})\}. \tag{8}$$

This is the rigorous and perfectly general expression for gamma, that is to say, valid for no matter how strong an absorption and for any elementary exposure law $f(E)$. Such also is (6), the equation of the slope curve.

This settles the direct problem. Now for the inverse problem: Given D for all E, find $f(E)$.

The density D as function of E is given; so, therefore, is the slope $g(E)$. Thus, if we put

$$-g(E)\cdot\mathrm{Log}\ T=G(E),$$

i.e., $ka\cdot ED'(E)=G(E)$, we have, by (5) or (6),

$$f(E)-f(TE)=G(E), \tag{9}$$

which is a kind of "functional equation" for the unknown function $f(E)$, with T a given constant and $G(E)$ a given function. The solution of the original "integral equation" (1) for f is thus reduced to the solution of a much simpler functional equation (9): given G, find f.

Our Eq. (9) holds for all E, positive of course, and the parameter T therein is a proper positive fraction, so that, starting with any E whatever, we have in E, TE, T^2E, etc., a decreasing geometrical sequence of exposures, tending to zero and a sequence of G values also tending to zero, since $G(o)=0$. Notice that for $E=o$ the Eq. (9) is satisfied identically, thus leaving the value of $f(o)$ free. But as we have already done before, we shall assume $f(o)=0$. (No exposure, no density.)

Keeping this in mind, write down (9) for a geometrical sequence of exposures, E, TE, T^2E, etc., thus:

$$\begin{aligned} f(E)-f(TE)&=G(E),\\ f(TE)-f(T^2E)&=G(TE),\\ &\cdots\cdots\cdots\\ &\cdots\cdots\cdots\\ f(T^nE)-f(T^{n+1}E)&=G(T^nE), \end{aligned}$$

and add all these $n+1$ equations. Then

$$f(E)-f(T^{n+1}E)=G(E)+G(TE)+\cdots+G(T^nE).$$

Now pass to the limit, for $n\to\infty$. Then the second term on the left hand will tend to $f(o)=0$, so that

$$f(E)=G(E)+G(TE)+G(T^2E)+\cdots \tag{10}$$

or, briefly,

$$f(E)=\sum_{i=0}^{\infty}G(T^iE), \tag{10}$$

an infinite series for $f(E)$. This, then, solves the inverse problem. The series (10) is convergent. In fact, a sufficient condition for convergency is that, from a high enough exponent n onwards,

$$G(T^{n+1}E) : G(T^nE) \leqslant \alpha, \text{ where } \alpha < 1,$$

and such is certainly the case of all actual photographic slope-curves. In practical applications of (10), a few terms of the series will already give a sufficiently accurate value of f, the fewer the smaller the transmittance T or the stronger the absorption.

While (10) is *a* solution of (9), it is by no means the only solution, so far as the abstract mathematician is concerned. For we can, manifestly, add to the solution (10) any function h satisfying the homogeneous equation:

$$h(E) - h(TE) = 0,$$

or $h(TE) = h(E)$, that is to say, any *periodic* function of E with multiplicative period T or of Log E with just the period Log T, and of a perfectly arbitrary form within any such period. In photography, however, such periodical or oscillatory H and D curves have no existence, so that the only admissible solution of the last equation is $h = \text{const.}$, and since the total f has to vanish for $E = 0$, we are driven to $h = 0$.

In fine, the only solution of photographic interest is (10) itself. The series will converge the more rapidly the stronger the absorption or the smaller the transmittance T of the emulsion coating. If $T = \frac{1}{2}$, say, then $f(E) = G(E) + G(\frac{1}{2}E) + G(\frac{1}{4}E) + \cdots$, and the series as it stands will be most convenient for numerical computation.

If, however, T differs but little from unity, say $T = 0.90$ or 0.95 (as frequently occurs), the convergence of our series will be very slow, so as to make its use impracticable. Under such circumstances another, more convenient, approximate expression for $f(E)$ can be derived from (9) differentially. In fact, let $T = 1 - \epsilon$, where ϵ is a small fraction. Then, assuming that f is an analytical function

$$f(TE) = f(E) - \epsilon E f'(E) + \frac{\epsilon^2 E^2}{2!} f''(E) - \cdots$$

and (9) becomes

$$\epsilon E f'(E) - \frac{\epsilon^2 E^2}{2} f''(E) + \cdots = G(E)$$
$$= -\log(1-\epsilon) E D'(E) = \epsilon\left(1 + \frac{\epsilon}{2} + \cdots\right) E D'(E).$$

If we retained only the first power of ϵ, the result would be $f(E) = D(E)$, showing no effect of absorption. If we include also the ϵ^2 terms, but no higher ones, then, dividing out by ϵE,

$$f'(E) - \frac{\epsilon E}{2} f''(E) = \left(1 + \frac{\epsilon}{2}\right) D'(E).$$

In the second term which already has ϵ as a factor, we may replace $f''(E)$ by its first approximation $D''(E)$. Thus

$$f'(E) = D'(E) + \tfrac{1}{2}\epsilon[D'(E) + E D''(E)],$$

and since the last bracket is $(d/dE)(ED')$,

$$f(E) = D(E) + \frac{\epsilon}{2} E D'(E), \qquad (11a)$$

which is the required expression up to ϵ^2 terms. To include these also we must retain in the original expansion the ϵ^3 terms. The result then is

$$f(E) = D(E) + \frac{\epsilon}{2} E D'(E) + \frac{\epsilon^2 E}{3}[D'(E) + \tfrac{1}{4} E D''(E)]. \qquad (11)$$

This will be sufficiently accurate for $\epsilon = 0.1$ and even 0.2 or 0.3. For still greater values of ϵ, its supplement T will be small enough to make the application of the series (10) more convenient.

This settles, essentially, all questions connected with the inverse problem.

Turning once more to the "direct" problem, let us now suppose the function $f(E)$ given and let us derive from the rigorous formulae (6) to (8) the effect upon the H and D curve, upon the position of its inflection point, and upon γ of a weak absorption, i.e., retaining ultimately only terms of the lowest surviving order in $\epsilon = 1 - T$. These effects will be denoted by δD, etc.

The effect on D at any exposure, may be derived directly from (11a) which gives $D = f$

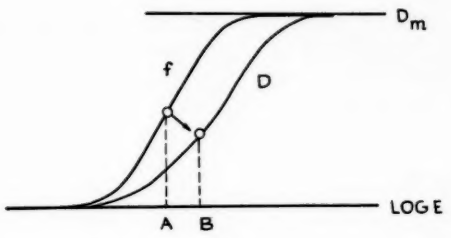

FIG. 1.

$-(\epsilon/2)ED'$; and since, up to terms in ϵ, $D'=f'$, the required effect $\delta D=D-f$ is

$$\delta D(E)=-\frac{\epsilon}{2}Ef'(E). \tag{12.1}$$

Next as to the position of the inflection point or its coordinates $\bar{E}$ and $\bar{D}=D(\bar{E})$. The inflection exposure $\bar{E}_0$ in absence of absorption ($\epsilon=0$) is determined by

$$f'(\bar{E}_0)+\bar{E}_0f''(\bar{E}_0)=0,$$

while $\bar{E}$ is determined rigorously by (7), i.e., by

$$f'(\bar{E})=(1-\epsilon)f'(\bar{E}-\epsilon\bar{E}).$$

Thus, developing the right-hand member up to ϵ^3 and dividing by ϵ, a factor of all surviving terms,

$$f'(\bar{E})+\bar{E}f''(\bar{E})=\epsilon\bar{E}_0[f''(\bar{E}_0)+\tfrac{1}{2}\bar{E}_0f'''(\bar{E}_0)],$$

where in the last two terms, which have ϵ as a factor, $\bar{E}$ has been replaced by $\bar{E}_0$. On the left-hand,

$$f'(\bar{E})=f'(\bar{E}_0)+f''(\bar{E}_0)\delta\bar{E},$$
$$f''(\bar{E})=f''(\bar{E}_0)+f'''(\bar{E}_0)\delta\bar{E}.$$

Hence, omitting the argument of f', etc., which is now throughout $\bar{E}_0$,

$$f'+f''\delta\bar{E}+(\bar{E}_0+\delta\bar{E})[f''+f'''\cdot\delta\bar{E}]=\epsilon\bar{E}_0[f''+\tfrac{1}{2}\bar{E}_0f'''],$$

and since $f'+\bar{E}_0f''=0$, this reduces to

$$[2f''+\bar{E}_0f''']\delta\bar{E}=\epsilon\bar{E}_0[f''+\tfrac{1}{2}\bar{E}_0f'''].$$

Thus, finally,

$$\delta\bar{E}=\tfrac{1}{2}\epsilon\bar{E}_0, \tag{12.2}$$

or $\delta(\log\bar{E})=\frac{1}{2}\epsilon$. The inflection point is shifted towards higher exposures. The variation of its ordinate $\bar{D}=D(\bar{E})$ follows directly from (12.1) by merely substituting $E=\bar{E}$ on the left-hand and noticing that on the right-hand $\bar{E}\doteq\bar{E}_0$ to the desired order of approximation. Thus,

$$\delta\bar{D}=-\frac{\epsilon}{2}\bar{E}_0f'(\bar{E}_0), \tag{12.3}$$

which, by (12.2), may be written

$$\delta\bar{D}=-f'(\bar{E}_0)\cdot\delta\bar{E}.$$

The inflection point is thus shifted forward and downwards. The whole D curve, moreover, lies under the f curve, coinciding with it, asymptotically, only at $E=\infty$ and at $E=o$. See the sketch in Fig. 1 (with Log E as abscissae), where the inflection point is marked by an eyelet. Its horizontal shift is

$$AB=\delta\ \text{Log}\ \bar{E}=\frac{M}{2}\epsilon=-\tfrac{1}{2}\ \text{Log}\ T,$$

to our order of approximation.

Lastly, for the variation of γ, we have, by (8),

$$\gamma=\frac{f(\bar{E})-f(\bar{E}-\epsilon\bar{E})}{-M\log(1-\epsilon)}\doteq\frac{\bar{E}f'(\bar{E})-\frac{1}{2}\epsilon\bar{E}^2f''(\bar{E})}{M(1+\frac{1}{2}\epsilon+\frac{1}{3}\epsilon^2)}.$$

If we retained in the last numerator only terms in ϵ, the result would be

$$\gamma=\frac{\bar{E}_0}{M}f'(\bar{E}_0)=\gamma_0.$$

In fine, there is no first-order effect on γ. Retaining also terms in ϵ^2 and recalling that $\bar{E}_0f''(\bar{E}_0)=-f'(\bar{E}_0)$ is the equation of the inflection point of the absorption curve and

$$\frac{1}{M}\bar{E}_0f'(\bar{E}_0)$$

its gamma, γ_0, the reader will find, after some reductions,

$$\delta\gamma=-\frac{\epsilon^2}{24}\left(2-\frac{f'f'''}{f''^2}\right)\gamma_0, \tag{12.4}$$

up to terms of higher order. Since γ_0 is a *maximum*, the bracketed expression can never be negative. Thus γ is always lowered by the absorption, though rather weakly, its logarithmic decrement being of the order

$$-\delta\log\gamma=\epsilon^2/24.$$

If, for instance, $T=0.50$ or $\epsilon=\frac{1}{2}$,[4] then γ is lowered by $\gamma_0/96$ or by little more than 1 percent.

Such, then, are the variations of density at any exposure, of the position of the inflection point, and of gamma due to a weak absorption. See formulae (12.1) to (12.4). With equal ease the reader may find the higher-order terms of these variations which may be needed if ϵ exceeds a few tenths or approaches unity. But then the rigorous formulae (6) to (8), with $f(E)$ given

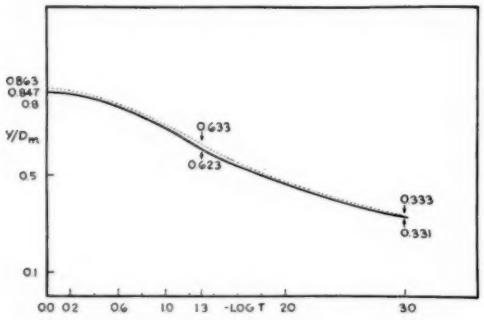

FIG. 2. γ/D_m as function of $-\text{Log } T$, for $f(E)=D_m(1-e^{-cE})$, solid curve; γ/D_m as function of $-\text{Log } T$, for $f(E)=D_m\frac{c^3E^2(3+cE)}{(1+cE)^3}$, dotted curve.

analytically or graphically, will be found more convenient.

To give at least one concrete application of the rigorous gamma expression (8), which will enable us also to find the effect on γ of a very strong absorption ($\epsilon\to1$ or T very small), let us develop that expression for some definite form of the elementary exposure law $f(E)$. To take the simplest form worth considering at all in photography, let

$$f(E)=D_m(1-e^{-cE}), \tag{13}$$

where c is a constant. Such, e.g., would be the exposure law according to the quantum theory, for an emulsion consisting of equal grains, each requiring a single quantum for its developability. We do not, however, commit ourselves to the practical acceptance of such a simple law, but use it only to illustrate the working of our general formulae which are independent of the quantum theory and, in fact, of any theory of exposure, being based only on the additivity of densities.

From (13) follows $f'(E)=cD_me^{-cE}$, so that the Eq. (7) of the inflection point becomes

$$e^{-c\tilde{E}}=Te^{-cT\tilde{E}},$$

whence

$$c\tilde{E}=-\text{Log } T/(1-T), \tag{14}$$

and by (8),

$$\gamma/D_m=-\frac{1}{\text{Log } T}(e^{-Tc\tilde{E}}-e^{-c\tilde{E}}),$$

or, since $e^{\text{Log } T}=T$,

$$\gamma/D_m=-\frac{1}{\text{Log } T}[S^T-S],\quad S=T^{1/1-T}. \tag{15}$$

This holds rigorously for any T, from unity down to zero. When $T=1-\epsilon$ tends to unity or $\epsilon\to0$, we have, by (14), $c\tilde{E}_0=1$, which follows also directly from (13), and $\gamma_0/D_m=(e^\epsilon-1)/Me\epsilon$.[5]

In fine, in the absence of absorption,

$$\gamma_0/D_m=1/Me=0.8471, \tag{15$_0$}$$

which follows also easily from (13).

To see the effect of absorption of any strength, let us compute γ/D_m, by (15), for a number of smaller and smaller transparencies. The results are gathered in Table I. Notice that, for ever decreasing T, the number S tends to zero, S^T to unity, and $\gamma/D_m\doteq-1/\text{Log } T\to0$. For $T=10^{-4}$, $\gamma/D_m=\frac{1}{4}$, etc., to all purposes. A graph of this table, with $-\text{Log } T$ as abscissae, is given in Fig. 2. In accordance with (12.4), the curve γ/D_m, Log $1/T$ starts of course horizontally. In much the same way the reader may treat the case of any other prescribed form $f(E)$ of the elementary (absorptionless) exposure law. He will find that the shape of the corresponding curve is not much influenced by the form of that law; only its initial ordinate γ_0/D_m may vary

TABLE I.

T	1.000	0.90	0.75	0.50	0.25	0.10	0.05	0.01	0.001
$-\text{Log } T$	0.000	0.046	0.125	0.301	0.602	1.000	1.301	2.000	3.000
γ/D_m	0.8471	0.847	0.845	0.831	0.785	0.697	0.623	0.473	0.331

[4] When, as we shall see presently from a concrete example, the approximation (12.4) is still close enough.

[5] If, pushing the approximation a few steps higher, we write $c\tilde{E}=1+\epsilon/2+\epsilon^2/3$, then the result is $\gamma=\gamma_0(1-\epsilon^2/24)$, agreeing with (12.4), valid for any form of $f(E)$. For, in the present case, $2-f'f'''/f''^2=1$, at the inflection point $\tilde{E}_0=1/c$.

considerably. Another example, moreover, is ready in my former paper (formulae 7 and 8.3). Namely, if

$$f(y)=D_m\frac{y^2(3+y)}{(1+y)^3},\quad y=cE,^6 \tag{16}$$

then

$$\frac{\gamma}{D_m}=\frac{(3+\sqrt{T})T-(1+3\sqrt{T})}{\text{Log } T\cdot(1+\sqrt{T})^3}. \tag{17}$$

The corresponding curve, which starts with $\gamma_0/D_m=3/8M=0.8633$, is also drawn in Fig. 2, as a dotted curve. The difference between the two curves is barely perceptible in spite of the fact that they are based on elementary laws as different in form as (13) and (16).

To conclude this paper, we may give a graphical illustration of the solution (10) of the inverse problem for the case of $T=\frac{1}{2}$, i.e.,

$$f(E)=G(E)+G(\tfrac{1}{2}E)+G(\tfrac{1}{4}E)+\cdots. \tag{10a}$$

In Fig. 3, the function $G(E)$, which differs from the slope $g(E)$ only by the numerical factor $-\text{Log } T=0.301$, is given by the bell-shaped curve with maximum ordinate 1, in arbitrary units. This curve belongs to a density-exposure curve of the type

$$D=\frac{D_m}{2}\left\{1+\Phi\left(\frac{cE-r}{\sqrt{2cE}}\right)\right\},$$

$$\Phi(x)=\frac{2}{\sqrt{\pi}}\int_0^x \exp(-u^2)du,$$

[6] This holds under the two-quanta hypothesis for an emulsion with an exponential size-frequency distribution.

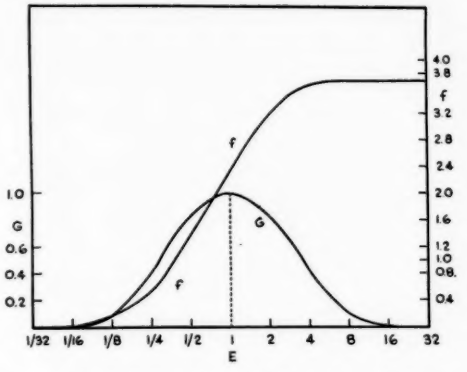

FIG. 3. $T=\frac{1}{2}$; $f(E)=G(E)+G(\frac{1}{2}E)+G(\frac{1}{4}E)+G(\frac{1}{8}E)+\cdots$.

which was found to cover the actual H and D curves of many emulsions. The construction of $f=f(E)$ from the given curve, by (10*a*), is very simple. To find f for $E=1$, for instance, we have to add together the ordinates G erected at $E=1$, $\frac{1}{2}$, $\frac{1}{4}$, and so on. Thus, to two decimals,

$$f(1)=1+0.82+0.41+0.09+0.01=2.33.$$

For $f(\frac{1}{2})$ we have only to omit the first item of this sum. Thus $f(\frac{1}{2})=1.33$, and similarly for $f(\frac{1}{4})$, and so on. For $f(2)$, we have only to add again the second term 0.82 (the G-curve being symmetrical), so that $f(2)=3.15$, and so on. In this manner the curve $f=f(E)$ has been constructed, in a conveniently reduced scale of ordinates, as explained in Fig. 3. This example will suffice to show that the process (10) of finding the law $f(E)$ is by no means cumbersome.

Temperature and Interrupted Photographic Exposure

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LONG, Germann, and Blair[1] observed that if certain photographic emulsions are exposed to long wave-length radiation, then allowed to rest in darkness, then re-exposed to the same radiation, the second exposure may for a short time reduce the developable density produced by the first. Evidence presented earlier by the same authors[2] suggested the existence of this phenomenon.

This paper deals with the effect of the temperature at which the emulsion is stored between the first and second exposures upon this regression. It has been suggested that during a photographic exposure two processes are taking place simultaneously—one an image forming process and the other an image destroying process. The density forming process according to the mechanism of Gurney and Mott[3] is the formation of metallic silver specks; the reverse process is the removal of electrons from the latent image and the resultant migration of the ions into interstitial spaces in the crystal lattice. It seems that during a rest period, changes take place in the exposed grains which cause the reverse process to predominate during the early part of the second exposure. Often a considerable amount of second exposure must be given before the grains are again in the former state and the density forming process can predominate. Person and Blair[4] have presented evidence which indicated that the reverse process is accelerated by rise of temperature. This might indicate that the regression during the second exposure might be accelerated by heating during the rest period.

EXPERIMENTAL

A 1000-watt Mazda lamp was mounted in a housing; 60 cm in front of it was placed a Wratten Safelight filter number 00; 15 cm behind the filter was mounted a sheet of Azo 0 paper. Successive strips of the paper parallel to its longer dimension were given increasing exposures to this radiation. The paper was then stored in darkness at a specified temperature for 1 hr., then remounted in the plate holder, and suc-

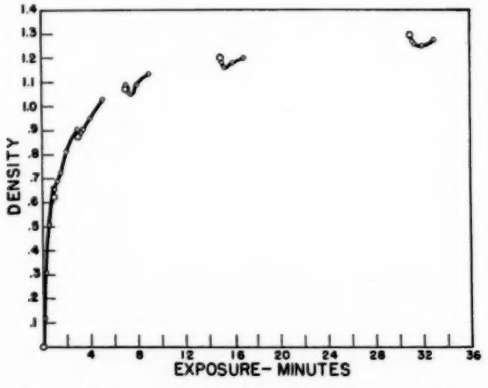

FIG. 1. The large circles show the developable density produced by exposure to light. The smaller circles show the changes in density during a second exposure to the same radiation provided the emulsion was stored for 1 hr. at 45° between the two exposures.

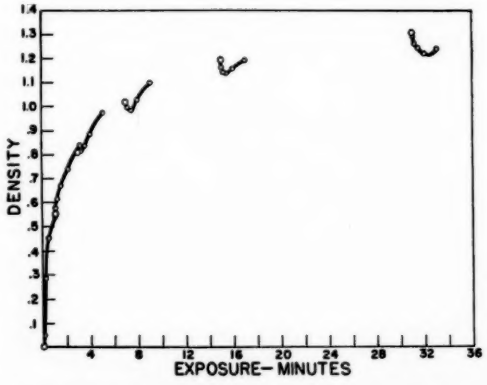

FIG. 2. The large circles show the developable density produced by exposure to light. The smaller circles show the changes in density during a second exposure to the same radiation provided the emulsion was stored for 1 hr. at 60° between the two exposures.

[1] Long, Germann, and Blair, "Concerning interrupted photographic exposure," J. Opt. Soc. Am. **25**, 382 (1935).
[2] Long, Germann, and Blair, "Intermittency and the Herschel effect," J. Phys. Chem. **39**, 721 (1935).
[3] N. F. Mott, "The photographic latent image," Phot. J. **81**, 63 (1941).
[4] F. G. Person and J. M. Blair, "Concerning the Herschel effect," J. Frank. Inst. **225**, 73 (1938).

cessive strips parallel to the shorter dimensions were given increasing exposures to the same radiation.

The sheets were then developed and finished in the usual manner. The normal reflection densities were then determined with a photoelectric densitometer. These densities are shown in Figs. 1–3 for three different storage temperatures. There the larger circles indicate the growth of developable density during the first exposure, the smaller circles show the changes in this density during the second exposure.

These figures show that the higher densities regress while the lower ones do not. Perhaps with more latent image there are more grains subject to the reverse process. The figures also show that the lowest density at which the image regresses during the second exposure decreases with rising temperature. Seven other tests were made with rest periods at varying temperatures between 20° and 80°. They showed more clearly that with increasing temperature during the rest period the net regression took place at lower densities. When the lowest density at which net regression took place was plotted against the temperature of storage, these points formed approximately a straight line. Extrapolation of this line to density 0 indicated that net regression would take place at any density after storage at 180°. Extrapolation of the line to the maximum density of the paper indicated that regression would not take place at any density after storage at 0°. Experimental data at 180° was not obtained because of the very rapid regression of the latent image during the period of heating. Paper stored at 0° showed no regression during a second exposure.

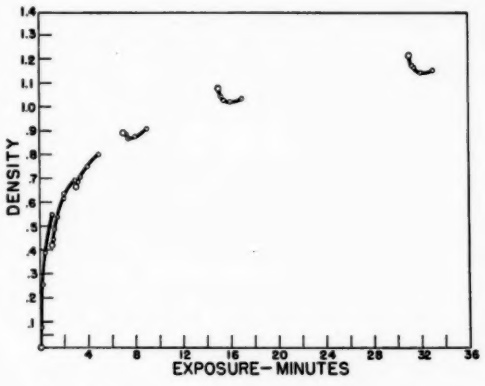

FIG. 3. The large circles show the developable density produced by exposure to light. The smaller circles show the changes in density during a second exposure to the same radiation provided the emulsion was stored for 1 hr. at 80° between the two exposures.

Tests were made with shorter rest periods at 80°. After a 1-minute rest period little regression was observed during a second exposure, and only above a density of 1.35. A two-minute rest period at 80° caused a regression at all densities above 0.9.

First Spark Spectrum of Thorium—Classification and Zeeman Effect Data of Th II

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(Received April 15, 1942)

Five sets of exposures to the thorium arc in silver, burning in a Bitter electromagnet at fields up to 93,000 oersteds, have given resolved Zeeman patterns for more than 800 lines of Th II. Data obtained from these plates, measured with an automatic comparator and used in connection with improved wave-length measurements, have made possible classification of 1091 lines of Th II as arising from 219 levels. These levels belong to two groups of terms between which no combinations have been found. Group A contains even terms arising from d^3s (with $a^4F_{1\frac{1}{2}}$ lying lowest), from d^3, and from ds^2, and odd terms from d^2p, dsp, and fds. About half of all terms expected from these configurations have been identified. Group B contains odd terms expected from fs^2 (with $a^2F^\circ_{2\frac{1}{2}}$ lying lowest), and fds, and even terms from fsp and fdp. g values are given for all levels, in many cases to within 0.002 unit, which makes available a large amount of fairly exact experimental data for evaluation of perturbations. Partial tests of the g sum rule show good agreement with theory, though all terms are not yet available for inclusion. Perturbations of even those terms which lie low are rather large.

THE spectra of thorium ($Z=90$) are complex. 2587 strong lines of thorium are listed in the *M.I.T. Wavelength Tables*,[1] and the M.I.T. card catalog shows that only the stronger lines have been studied carefully. Lier[2] has published a thesis describing the thorium spectra, and gives an excellent summary of previous work done in obtaining wave-length and other data basic to any attempt at classifying the spectra. Lier gives the results of Zeeman effect measurements made at fields of 40,000 oersteds and reports resolved-pattern measurements for 17 lines of Th I, 64 of Th II, and 37 of Th III, together with data on a large number of unresolved triplets. He also gives a small quadratic array for Th III, which accounts for 37 lines.

R. J. Lang[3] also has discovered a number of regularities in Th III, the spectrum of which extends into the far ultraviolet beyond 200A. Lang has classified 56 lines of Th III, including many strong lines lying between 3000 and 2200A, and gives 24 energy levels. Lang[4] has also classified the main lines of Th IV into a single-electron doublet system. These lines are scattered throughout the spectrum from 2700 to 580A.

The M.I.T. card catalog shows that approximately 2000 lines in the range 10,000 to 2000A have been identified by previous workers as arising from the singly-ionized thorium atom, Th II. No analysis of this spectrum appears to have been reported. It can be expected to contain doublets and quartets built on the singlets and triplets of Th III.

The object of the present paper is to put on record a preliminary analysis of Th II at which we have arrived after utilizing improved wave-length measurements and studying the Zeeman effect of Th II at fields up to 93,000 oersteds. At such high fields we have been able to obtain resolved patterns on more than 800 lines of Th II, and as a result have been able to classify 1091 lines as arising from 219 levels, which fall into two groups between which no combinations have been found. This duplicity holds also for certain of the rare earths,[5] presumably because of the fact that all combination lines lie in the inaccessible infra-red. Our efforts to extend the Th II classification further must be interrupted for the time being.

EXPERIMENTAL METHODS

Five sets of exposures, each on twelve or sixteen 2 in.×20 in. plates, were made for the purpose of studying the Zeeman effects of thorium in the range 2000 to 7000A, using the new technique which has been developed with the Bitter

[1] *M.I.T. Wavelength Tables* (John Wiley & Sons, New York, 1939).
[2] J. N. Lier, "Thorium spectra en hun Zeeman-effect," Thesis Amsterdam, 1939. See also T. L. de Bruin and J. N. Lier, Proc. Kon. Acad. Amst. **41**, 956 (1938).
[3] R. J. Lang, Phys. Rev. **56**, 272 (1939).
[4] R. J. Lang, Can. J. Research **A14**, 43 (1936).
[5] G. R. Harrison, W. E. Albertson, and N. F. Hosford, J. Opt. Soc. Am. **31**, 439 (1941).

TABLE I. Th II classified lines, group A.

Wave-length	Arc int.	Wave number	Classification	Type	Sep.	p	n	g_1	g_2
8143.15	4	12276.89	$b^4P_{\frac{1}{2}}-y^2P^o_{\frac{1}{2}}$						
7900.35	2	12654.19	$a^2P_{1\frac{1}{2}}-y^2F^o_{2\frac{1}{2}}$						
6993.08	15	14295.91	$a^2D_{1\frac{1}{2}}-z^2F^o_{2\frac{1}{2}}$						
6703.97	2	14912.42	$b^2D_{1\frac{1}{2}}-y^2P^o_{1\frac{1}{2}}$						
6692.68	2	14937.58	$b^4F_{2\frac{1}{2}}-z^4F^o_{1\frac{1}{2}}$						
6658.681	4*h*	15013.85	$b^2D_{2\frac{1}{2}}-x^2D^o_{1\frac{1}{2}}$						
6633.38	2*s*	15071.12	$a^4P_{2\frac{1}{2}}-z^2F^o_{1\frac{1}{2}}$						
6619.877	3	15101.86	$a^4F_{2\frac{1}{2}}-z^2D^o_{2\frac{1}{2}}$						
6605.432	5*h*	15134.88	$b^4F_{2\frac{1}{2}}-z^2D^o_{2\frac{1}{2}}$						
6511.38	2*h*	15353.49	$a^4P_{2\frac{1}{2}}-z^2D^o_{1\frac{1}{2}}$						
6511.00	4	15354.39	$a^4P_{1\frac{1}{2}}-y^2P^o_{1\frac{1}{2}}$						
6416.101	3	15581.49	$b^2D_{2\frac{1}{2}}-z^2G^o_{3\frac{1}{2}}$	4	—	(0)	885	(1.034)	0.990
6408.598	4	15599.73	$a^4F_{2\frac{1}{2}}-z^2F^o_{1\frac{1}{2}}$	4	204	(103)	766	1.072	1.276
6379.22	—	15671.57	$b^2D_{1\frac{1}{2}}-z^2F^o_{1\frac{1}{2}}$						
6323.81	2	15808.89	$a^2F_{2\frac{1}{2}}-x^2D^o_{1\frac{1}{2}}$						
6309.48	2	15844.79	$a^2D_{2\frac{1}{2}}-z^2F^o_{2\frac{1}{2}}$						
6304.240	6	15857.96	$a^2F_{2\frac{1}{2}}-y^2D^o_{2\frac{1}{2}}$						
6277.249	10	15926.15	$a^4F_{4\frac{1}{2}}-z^2G^o_{4\frac{1}{2}}$	6	222	(994)	1205	1.315	1.093
6274.109	25	15034.12	$a^4F_{3\frac{1}{2}}-z^2F^o_{3\frac{1}{2}}$	6	92	(320)	1188	1.235	1.143
6266.169	8	15954.31	$b^2D_{1\frac{1}{2}}-z^2D^o_{1\frac{1}{2}}$	6	137	(206)	1038	.970	1.107
6261.063	15	15967.32	$b^4F_{2\frac{1}{2}}-z^2F^o_{2\frac{1}{2}}$	5	—	(0)	1115	(1.163)	1.149
6232.970	10	16039.29	$b^2D_{2\frac{1}{2}}-z^2D^o_{2\frac{1}{2}}$	6	102	—	1090	1.038	1.140
6145.271	5	16268.18	$a^2F_{2\frac{1}{2}}-y^2F^o_{2\frac{1}{2}}$						
6112.822	15	16354.54	$b^4F_{4\frac{1}{2}}-z^2D^o_{3\frac{1}{2}}$	6	290	(435)	729	0.584	0.874
6104.569	12	16376.65	$a^2F_{2\frac{1}{2}}-z^2G^o_{3\frac{1}{2}}$	7b	—	(0)	982	0.982	0.982
6097.26	2	16396.28	$a^4F_{4\frac{1}{2}}-z^2D^o_{4\frac{1}{2}}$						
6085.248	6	16428.65	$a^4F_{4\frac{1}{2}}-z^2H^o_{5\frac{1}{2}}$	6	269	(1207)	1172	1.308	1.039
6058.55	2	16501.04	$a^2P_{1\frac{1}{2}}-w^2P^o_{1\frac{1}{2}}$						
5989.035	20	16692.57	$a^4F_{3\frac{1}{2}}-z^2D^o_{2\frac{1}{2}}$	5	199	(100)	1374	1.075	0.876
5981.79	5	16712.79	$a^2G_{4\frac{1}{2}}-w^2D^o_{3\frac{1}{2}}$	4	216	(109)	414	.945	1.161
5976.439	10	16727.75	$b^2D_{1\frac{1}{2}}-w^2D^o_{1\frac{1}{2}}$						
5948.59	5*s*	16806.06	$b^2D_{1\frac{1}{2}}-z^2P^o_{1\frac{1}{2}}$						
5938.582	6	16834.38	$a^2F_{2\frac{1}{2}}-x^2D^o_{2\frac{1}{2}}$	6	153	(382)	1063	0.988	1.141
5872.54	10	17023.70	$b^2D_{2\frac{1}{2}}-w^2D^o_{2\frac{1}{2}}$						
5838.951	12	17121.63	$a^4F_{4\frac{1}{2}}-z^2F^o_{4\frac{1}{2}}$	6	639	(958)	956	0.639	1.278
5822.58	2	17160.77	$a^4P_{1\frac{1}{2}}-w^2D^o_{1\frac{1}{2}}$						
5817.69	2	17184.20	$b^4F_{2\frac{1}{2}}-z^2F^o_{2\frac{1}{2}}$						
5815.432	18*d*	17190.87	$b^4F_{4\frac{1}{2}}-z^4F^o_{4\frac{1}{2}}$	6	301	(456)	738	0.586	0.887
5795.99	10	17248.54	$a^4P_{1\frac{1}{2}}-z^2P^o_{1\frac{1}{2}}$						
5749.379	12*d*	17388.37	$b^4F_{4\frac{1}{2}}-z^2D^o_{3\frac{1}{2}}$	5	344	(172)	1450	0.592	0.936
5741.162	10	17413.26	$a^2D_{1\frac{1}{2}}-z^2D^o_{1\frac{1}{2}}$	6	304	(452)	924	0.774	1.078
5738.26	5	17422.06	$a^4P_{1\frac{1}{2}}-z^2D^o_{2\frac{1}{2}}$						
5725.031	6	17462.32	$a^2D_{1\frac{1}{2}}-y^2D^o_{2\frac{1}{2}}$						
5712.54	2	17500.50	$a^2P_{1\frac{1}{2}}-z^2P^o_{1\frac{1}{2}}$						
5707.094	20	17517.20	$a^4F_{4\frac{1}{2}}-y^2G^o_{4\frac{1}{2}}$	6	126	(565)	1256	1.315	1.189
5639.733	12	17726.43	$a^4F_{3\frac{1}{2}}-z^2D^o_{2\frac{1}{2}}$	6	145	(359)	1004	1.076	0.931
5593.615	10	17872.58	$a^2D_{1\frac{1}{2}}-y^2F^o_{2\frac{1}{2}}$	5	284	(145)	1503	0.793	1.077
5556.17	2	17993.02	$a^4F_{4\frac{1}{2}}-z^2G^o_{4\frac{1}{2}}$						
5501.938	10	18170.38	$a^4P_{\frac{1}{2}}-z^2D^o_{1\frac{1}{2}}$						
5488.622	10	18214.46	$a^4F_{1\frac{1}{2}}-z^2D^o_{1\frac{1}{2}}$						
5421.837	8	18438.82	$a^2D_{1\frac{1}{2}}-z^2D^o_{2\frac{1}{2}}$	5	341	—	—	0.798	1.139
5318.423	8	18797.35	$a^2F_{2\frac{1}{2}}-v^2D^o_{1\frac{1}{2}}$						
5305.580	10	18842.85	$b^2D_{2\frac{1}{2}}-z^4F^o_{2\frac{1}{2}}$						
5289.895	6	18898.72	$b^4F_{2\frac{1}{2}}-y^2D^o_{1\frac{1}{2}}$	5	142	—	—	1.162	1.020
5255.52	2	19022.33	$a^4P_{\frac{1}{2}}-z^2P^o_{\frac{1}{2}}$						
5247.652	20*d*	19050.85	$a^4F_{1\frac{1}{2}}-z^4F^o_{1\frac{1}{2}}$	6	250	(377)	763	0.637	0.887
5193.820	8	19248.31	$a^4F_{1\frac{1}{2}}-z^2D^o_{2\frac{1}{2}}$	—	291	—	—	(.639)	.930
5190.870	10	19259.24	$b^4F_{2\frac{1}{2}}-y^2P^o_{1\frac{1}{2}}$	5	91	—	—	1.166	1.075
5151.620	4	19405.98	$a^2P_{1\frac{1}{2}}-z^4D^o_{\frac{1}{2}}$						
5143.264	10	19437.51	$b^4F_{4\frac{1}{2}}-z^2F^o_{3\frac{1}{2}}$	5	181	—	1042	0.591	0.772
5107.28	10	19574.45	$a^2P_{\frac{1}{2}}-v^2D^o_{1\frac{1}{2}}$						
5090.759	8	19637.98	$a^2F_{2\frac{1}{2}}-z^4F^o_{2\frac{1}{2}}$						
5085.12	2	19659.76	$a^4P_{2\frac{1}{2}}-w^2P^o_{1\frac{1}{2}}$						
5079.141	5	19682.90	$a^2D_{2\frac{1}{2}}-t^2D^o_{2\frac{1}{2}}$						
5055.342	2	19775.56	$a^4F_{2\frac{1}{2}}-z^2F^o_{2\frac{1}{2}}$						
4990.031	5	20034.38	$a^4P_{2\frac{1}{2}}-z^2F^o_{2\frac{1}{2}}$						
4972.609	3	20104.57	$a^2D_{2\frac{1}{2}}-w^2F^o_{2\frac{1}{2}}$						
4924.431	8	20301.26	$b^4F_{2\frac{1}{2}}-z^2D^o_{1\frac{1}{2}}$						
4912.529	12	20350.45	$b^4F_{2\frac{1}{2}}-y^2D^o_{2\frac{1}{2}}$						
4879.158	3	20489.63	$a^2F_{2\frac{1}{2}}-z^2F^o_{2\frac{1}{2}}$						
4844.759	3	20635.11	$b^2D_{1\frac{1}{2}}-x^2F^o_{2\frac{1}{2}}$						
4826.40	1	20713.61	$a^2P_{1\frac{1}{2}}-t^2D^o_{2\frac{1}{2}}$						
4823.184	3	20727.42	$a^4F_{2\frac{1}{2}}-y^2F^o_{2\frac{1}{2}}$						
4815.5	2*wh*	20760.49	$b^4F_{2\frac{1}{2}}-y^2F^o_{2\frac{1}{2}}$						
4790.451	1	20869.05	$b^4F_{2\frac{1}{2}}-z^2G^o_{3\frac{1}{2}}$						
4743.700	3	21074.72	$b^4F_{2\frac{1}{2}}-w^2D^o_{1\frac{1}{2}}$	5	226	—	1504	1.165	0.939
4726.339	2	21152.13	$b^4F_{1\frac{1}{2}}-y^2D^o_{1\frac{1}{2}}$						
4725.95	2*h*	21153.87	$b^4P_{1\frac{1}{2}}-y^4F^o_{1\frac{1}{2}}$						
4706.219	5	21242.55	$a^2D_{1\frac{1}{2}}-z^4F^o_{2\frac{1}{2}}$	5	121	(60)	1107	0.803	0.924
4702.320	4	21260.17	$a^2G_{4\frac{1}{2}}-z^4D^o_{3\frac{1}{2}}$						
4697.395	5*wh*	21282.46	$a^2G_{3\frac{1}{2}}-y^2G^o_{3\frac{1}{2}}$						
4694.919	3	21293.68	$a^4F_{3\frac{1}{2}}-z^2D^o_{2\frac{1}{2}}$						
4694.092	15	21297.43	$a^4F_{4\frac{1}{2}}-z^2F^o_{3\frac{1}{2}}$	5	127	(63)	956	0.640	0.767
4652.027	6	21490.01	$a^4F_{2\frac{1}{2}}-y^2D^o_{1\frac{1}{2}}$	5	—	(0)	1152	(1.076)	1.026
4629.772	3	21593.31	$b^2D_{2\frac{1}{2}}-y^2G^o_{3\frac{1}{2}}$						
4606.506	4	21702.37	$a^4P_{1\frac{1}{2}}-v^2P^o_{1\frac{1}{2}}$						
4602.884	5	21719.44	$a^2D_{1\frac{1}{2}}-w^2P^o_{1\frac{1}{2}}$	6	363	(542)	980	0.799	1.162
4575.246	2	21850.64	$a^4F_{2\frac{1}{2}}-y^2P^o_{1\frac{1}{2}}$	7b	—	(0)	1080	1.080	1.080
4566.645	6	21891.80	$a^2P_{\frac{1}{2}}-t^2P^o_{1\frac{1}{2}}$	4	265	(132)	853	1251	0.986
4566.249	1	21893.70	$b^4P_{1\frac{1}{2}}-y^4D^o_{\frac{1}{2}}$						
4526.031	3	22088.24	$a^2G_{3\frac{1}{2}}-y^2F^o_{2\frac{1}{2}}$						
4524.84	5	22094.05	$a^2D_{1\frac{1}{2}}-z^4F^o_{2\frac{1}{2}}$	5	200	—	1292	0.792	0.992
4488.680	25	22272.04	$b^4F_{1\frac{1}{2}}-z^2P^o_{1\frac{1}{2}}$						
4487.500	20	22277.89	$a^4F_{2\frac{1}{2}}-w^2D^o_{2\frac{1}{2}}$						
4480.822	25	22311.09	$b^4F_{2\frac{1}{2}}-w^2D^o_{2\frac{1}{2}}$	7b	—	(0)	1167	1.167	1.167
4465.345	30*s*	22388.43	$a^4F_{3\frac{1}{2}}-y^2G^o_{3\frac{1}{2}}$	5	213	(106)	1735	0.990	1.203
4461.085	10*d*	22409.80	$b^2F_{3\frac{1}{2}}-z^2D^o_{2\frac{1}{2}}$						
4447.845	12	22476.51	$a^4P_{\frac{1}{2}}-w^2P^o_{1\frac{1}{2}}$	4	953	(476)	686	2.116	1.163
4440.872	20	22511.81	$b^2D_{1\frac{1}{2}}-z^4D^o_{2\frac{1}{2}}$	5	251	(128)	1598	0.972	1.223
4422.783	6	22603.87	$b^4F_{1\frac{1}{2}}-y^2D^o_{2\frac{1}{2}}$						
4421.557	8	22610.14	$a^4F_{2\frac{1}{2}}-z^2P^o_{1\frac{1}{2}}$						
4400.387	6	22718.91	$a^2D_{1\frac{1}{2}}-v^2P^o_{1\frac{1}{2}}$						
4396.479	10	22739.11	$a^4P_{2\frac{1}{2}}-y^2F^o_{3\frac{1}{2}}$	4	251	(126)	543	1.424	1.173
4394.899	10	22747.28	$a^2F_{2\frac{1}{2}}-z^4D^o_{1\frac{1}{2}}$	5	126	(63)	1190	0.995	0.869
4388.413	8	22780.90	$b^4P_{\frac{1}{2}}-y^4D^o_{\frac{1}{2}}$						
4366.974	5	22892.74	$b^2D_{1\frac{1}{2}}-z^4D^o_{1\frac{1}{2}}$						
4357.587	8	22942.05	$a^4F_{2\frac{1}{2}}-y^2D^o_{2\frac{1}{2}}$	6	322	(802)	1235	1.070	1.392
4355.327	12	22953.96	$a^4P_{1\frac{1}{2}}-z^4D^o_{2\frac{1}{2}}$	4	390	(194)	1801	1.608	1.218
4344.334	12	23012.04	$a^4F_{1\frac{1}{2}}-y^2D^o_{1\frac{1}{2}}$	6	378	(566)	828	0.641	1.019
4343.954	10	23014.05	$b^4F_{1\frac{1}{2}}-y^2F^o_{2\frac{1}{2}}$	—	492	(244)	—	(0.586)	1.078
4308.260	3	23204.72	$a^2F_{2\frac{1}{2}}-t^2D^o_{2\frac{1}{2}}$						
4281.425	15	23350.16	$b^2D_{1\frac{1}{2}}-t^2D^o_{2\frac{1}{2}}$						
4281.072	20	23352.09	$a^4F_{2\frac{1}{2}}-y^2F^o_{3\frac{1}{2}}$	7b	—	(0)	1073	1.073	1.073
4277.322	20	23372.56	$a^4F_{1\frac{1}{2}}-y^2P^o_{1\frac{1}{2}}$	6	429	(641)	851	0.640	1.069
4271.103	5	23406.59	$b^4F_{1\frac{1}{2}}-z^2P^o_{\frac{1}{2}}$						
4263.359	10	23449.11	$b^2D_{2\frac{1}{2}}-u^2D^o_{2\frac{1}{2}}$	6	59	(147)	1064	1.035	1.094
4261.276	5	23460.57	$a^4F_{2\frac{1}{2}}-z^2G^o_{3\frac{1}{2}}$						
4249.685	12	23524.56	$a^2P_{\frac{1}{2}}-z^4D^o_{1\frac{1}{2}}$	4	392	(195)	661	1.250	0.858
4243.929	12	23556.46	$b^2D_{2\frac{1}{2}}-z^4F^o_{3\frac{1}{2}}$	5	—	(0)	1148	(1.034)	1.065
4242.725	5	23563.15	$a^2D_{1\frac{1}{2}}-x^2P^o_{\frac{1}{2}}$	5	250	(125)	918	0.793	0.543
4224.251	—	23666.17	$a^4F_{2\frac{1}{2}}-w^2D^o_{1\frac{1}{2}}$	5	139	(68)	1284	1.082	0.943
4201.852	8	23792.35	$a^4P_{1\frac{1}{2}}-v^2D^o_{2\frac{1}{2}}$	4	493	(247)	374	1.607	1.114
4183.574	8	23896.30	$a^4P_{2\frac{1}{2}}-z^4F^o_{3\frac{1}{2}}$	4	348	(175)	206	1.419	1.071
4179.718	8	23918.34	$a^4F_{2\frac{1}{2}}-z^2D^o_{2\frac{1}{2}}$	6	62	(154)	1070	(1.076)	1.138
4170.543	2	23970.96	$a^2D_{1\frac{1}{2}}-z^4D^o_{2\frac{1}{2}}$						
4148.182	10	24100.17	$a^2P_{\frac{1}{2}}-u^2D^o_{1\frac{1}{2}}$	4	362	(181)	708	1.252	0.890
4142.703	10	24132.05	$a^4F_{1\frac{1}{2}}-z^2P^o_{1\frac{1}{2}}$	6	788	(1181)	1039	0.643	1.431
4141.641	8	24138.24	$a^2H_{4\frac{1}{2}}-x^2G^o_{4\frac{1}{2}}$						
4138.82	—	24154.69	$a^4P_{2\frac{1}{2}}-u^2P^o_{1\frac{1}{2}}$						
4123.569	5	24244.02	$a^2F_{2\frac{1}{2}}-u^2D^o_{2\frac{1}{2}}$						
4110.640	5	24320.28	$a^4P_{\frac{1}{2}}-z^2P^o_{\frac{1}{2}}$	6	1554	(777)	1333	2.110	0.556
4109.395	2*h*	24327.64	$a^2F_{2\frac{1}{2}}-t^2D^o_{2\frac{1}{2}}$	6	127	(317)	—	(0.986)	1.113
4105.343	12	24351.65	$a^2D_{1\frac{1}{2}}-z^4D^o_{1\frac{1}{2}}$	6	64	(85)	833	0.801	0.865
4103.67	2*wh*	24361.58	$a^2P_{1\frac{1}{2}}-t^2P^o_{1\frac{1}{2}}$						
4098.939	10	24389.70	$b^2D_{1\frac{1}{2}}-u^2D^o_{2\frac{1}{2}}$	5	124	(62)	1282	0.972	1.096
4094.751	15	24414.64	$a^4F_{1\frac{1}{2}}-z^2D^o_{1\frac{1}{2}}$	6	468	(700)	866	0.635	1.103

TABLE I.—*Continued.*

Wave-length	Arc int.	Wave number	Classification	Type	Sep.	p	n	g_1	g_2
4086.520	12	24463.82	$a^4F_{1\frac{1}{2}}-y^6D^o_{2\frac{1}{2}}$	5	756	(377)	2532	0.637	1.393
4059.883	8	24624.33	$a^3D_{1\frac{1}{2}}-z^4D^o_{\frac{1}{2}}$						
4039.364	—	24749.40	$a^3F_{2\frac{1}{2}}-w^4F^o_{2\frac{1}{2}}$						
4036.567	15	24766.55	$b^4F_{1\frac{1}{2}}-y^6F^o_{\frac{1}{2}}$	7b	—	(0)	576	(0.586)	0.606
4034.256	10	24780.74	$a^4F_{\frac{1}{2}}-y^6G^o_{1\frac{1}{2}}$	5	114	(55)	1710	1.314	1.200
4029.310	8	24811.16	$b^2D_{2\frac{1}{2}}-e^2D^o_{2\frac{1}{2}}$						
4019.137	8	24873.96	$a^4F_{1\frac{1}{2}}-y^6F^o_{2\frac{1}{2}}$	5	441	(221)	1746	0.639	1.080
4014.533	—	24902.48	$a^4F_{2\frac{1}{2}}-w^2D^o_{2\frac{1}{2}}$						
4013.264	5	24910.36	$a^3P_{1\frac{1}{2}}-y^4D^o_{\frac{1}{2}}$						
4012.497	15	24915.12	$a^4P_{1\frac{1}{2}}-t^2D^o_{2\frac{1}{2}}$						
4010.50	—	24927.53	$a^2D_{1\frac{1}{2}}-w^2D^o_{1\frac{1}{2}}$						
4001.740	10	24982.09	$b^4F_{2\frac{1}{2}}-x^2F^o_{2\frac{1}{2}}$						
3981.539	3	25108.84	$a^4P_{\frac{1}{2}}-z^4D^o_{1\frac{1}{2}}$						
3969.003	10	25188.14	$a^4F_{1\frac{1}{2}}-w^2D^o_{1\frac{1}{2}}$						
3960.339	10	25243.25	$a^2D_{2\frac{1}{2}}-r^4D^o_{2\frac{1}{2}}$	6	27	(67)	1232	1.246	1.219
3956.682	10	25266.58	$a^4F_{1\frac{1}{2}}-z^6F^o_{\frac{1}{2}}$	4	86	(43)	590	0.633	0.719
3937.888	—	25367.17	$a^2P_{\frac{1}{2}}-w^2F^o_{1\frac{1}{2}}$	4	218	(109)	921	1.250	1.032
3938.732	15w	25381.72	$a^2P_{1\frac{1}{2}}-y^4D^o_{1\frac{1}{2}}$						
3929.671	30	25440.25	$a^4F_{1\frac{1}{2}}-x^2D^o_{2\frac{1}{2}}$	5	500	(251)	1887	0.638	1.138
3913.826	10	25543.25	$b^4F_{1\frac{1}{2}}-t^2D^o_{1\frac{1}{2}}$	6	416	(620)	795	0.583	0.999
3904.089	20	25606.94	$b^4F_{2\frac{1}{2}}-t^2F^o_{1\frac{1}{2}}$	5	174	(90)	1433	1.164	0.990
3901.158	10	25626.18	$a^2P_{1\frac{1}{2}}-y^4F^o_{2\frac{1}{2}}$						
3892.311	10	25684.43	$a^4P_{\frac{1}{2}}-u^2D^o_{1\frac{1}{2}}$	4	1230	(616)	279	2.122	0.892
3882.152	—	25751.64	$b^2D_{1\frac{1}{2}}-s^2D^o_{2\frac{1}{2}}$	—	177	(92)	—	(0.968)	1.145
3881.490	—	25756.03	$b^2D_{2\frac{1}{2}}-t^2F^o_{2\frac{1}{2}}$	6	43	(108)	1059	1.038	1.081
3826.947	10	26123.11	$b^4P_{\frac{1}{2}}-s^4D^o_{1\frac{1}{2}}$	6	1300	(650)	601	2.551	1.251
3823.589	5	26146.05	$a^2D_{2\frac{1}{2}}-x^4D^o_{2\frac{1}{2}}$	4	116	(57)	848	1.252	1.136
3823.327	5	26147.84	$b^4F_{\frac{1}{2}}-z^4D^o_{\frac{1}{2}}$						
3813.625	—	26214.36	$a^2D_{1\frac{1}{2}}-w^2F^o_{1\frac{1}{2}}$	6	233	(350)	915	0.799	1.032
3805.02	5	26273.64	$a^2P_{1\frac{1}{2}}-r^4D^o_{2\frac{1}{2}}$						
3793.488	20w	26353.51	$a^2D_{1\frac{1}{2}}-w^2F^o_{2\frac{1}{2}}$	5	154	(77)	—	0.798	0.952
3792.920	10	26357.45	$b^4F_{4\frac{1}{2}}-z^4G^o_{5\frac{1}{2}}$						
3789.116	20	26383.91	$b^4F_{1\frac{1}{2}}-z^4F^o_{2\frac{1}{2}}$	5	335	(167)	1423	0.587	0.922
3783.296	20	26424.50	$a^4F_{1\frac{1}{2}}-w^2D^o_{2\frac{1}{2}}$	—	530	(265)	—	(0.639)	1.169
3775.942	20	26475.97	$b^4P_{\frac{1}{2}}-x^4D^o_{\frac{1}{2}}$	6	2300	(1150)	1410	2.560	0.260
3772.252	10	26501.86	$a^2P_{\frac{1}{2}}-z^4F^o_{\frac{1}{2}}$	6	250	(125)	1384	1.259	1.509
3754.596	20	26626.48	$a^4F_{4\frac{1}{2}}-y^6F^o_{\frac{1}{2}}$	7b	—	(0)	648	(0.639)	.621
3744.739	15	26696.57	$b^2D_{1\frac{1}{2}}-t^2F^o_{2\frac{1}{2}}$	—	108	(53)	—	(0.968)	1.076
3741.190	80	26721.89	$a^4F_{2\frac{1}{2}}-z^4F^o_{2\frac{1}{2}}$	6	153	(380)	993	1.070	0.917
3738.846	20	26738.64	$b^2D_{1\frac{1}{2}}-w^2F^o_{\frac{1}{2}}$	7b	—	(0)	968	0.968	0.968
3726.730	30	26825.57	$a^4F_{3\frac{1}{2}}-z^4D^o_{2\frac{1}{2}}$	7b	—	(0)	1257	(1.232)	1.224
3723.655	—	26847.73	$a^4F_{3\frac{1}{2}}-y^2G^o_{3\frac{1}{2}}$	6	29	(102)	—	(1.232)	1.203
3722.117	—	26858.82	$b^4F_{3\frac{1}{2}}-z^4D^o_{3\frac{1}{2}}$	6	55	(137)	—	(1.163)	1.218
3721.831	40	26860.88	$b^4F_{1\frac{1}{2}}-w^2F^o_{1\frac{1}{2}}$	6	578	(865)	869	0.591	1.169
3720.309	15	26871.87	$a^2G_{3\frac{1}{2}}-z^4G^o_{3\frac{1}{2}}$	6	186	(650)	—	0.956	1.142
3705.94	8	26976.06	$a^2G_{3\frac{1}{2}}-z^4G^o_{2\frac{1}{2}}$						
3704.967	10	26983.14	$b^4P_{1\frac{1}{2}}-y^4D^o_{2\frac{1}{2}}$	—	414	(203)	—	(1.592)	1.178
3704.087	—	26989.55	$b^2D_{2\frac{1}{2}}-y^4F^o_{1\frac{1}{2}}$	5	207	(96)	1340	1.027	0.820
3700.771	15	27013.74	$a^2H_{4\frac{1}{2}}-z^4F^o_{4\frac{1}{2}}$	6	156	(701)	1086	1.010	1.166
3696.653	6	27043.83	$b^2D_{2\frac{1}{2}}-t^2D^o_{1\frac{1}{2}}$						
3678.035	10	7180.72	$b^2D_{2\frac{1}{2}}-t^2F^o_{1\frac{1}{2}}$	4	76	(38)	927	1.041	1.117
3678.035	10	27180.72	$a^4P_{1\frac{1}{2}}-w^2F^o_{\frac{1}{2}}$	5	630	(316)	1920	1.605	0.975
3677.741	5	27182.89	$b^2D_{2\frac{1}{2}}-z^4G^o_{3\frac{1}{2}}$						
3675.571	10	27198.94	$a^4F_{\frac{1}{2}}-w^2P^o_{1\frac{1}{2}}$	4	85	(42)	951	1.074	1.159
3670.635	5	27235.52	$b^4F_{1\frac{1}{2}}-z^2F^o_{2\frac{1}{2}}$						
3670.062	3d	27239.77	$b^4F_{2\frac{1}{2}}-z^4D^o_{1\frac{1}{2}}$	5	300	(154)	1613	1.165	0.865
3663.708	10	27287.01	$b^2D_{2\frac{1}{2}}-z^4G^o_{3\frac{1}{2}}$	7b	—	(0)	1039	1.039	1.039
3658.069	10	27329.07	$a^2D_{1\frac{1}{2}}-z^4P^o_{\frac{1}{2}}$	4	708	(353)	441	0.798	1.506
3652.542	10	27370.42	$a^2P_{\frac{1}{2}}-w^2P^o_{\frac{1}{2}}$	6	278	(139)	1113	1.252	0.974
3650.771	10	27383.70	$a^4P_{\frac{1}{2}}-t^2D^o_{1\frac{1}{2}}$	5	242	(120)	1787	1.423	1.181
3648.170	6	27403.22	$a^4F_{1\frac{1}{2}}-v^2D^o_{1\frac{1}{2}}$						
3632.626	6	27520.48	$a^4P_{2\frac{1}{2}}-t^2P^o_{1\frac{1}{2}}$	5	312	(158)	1891	1.426	1.114
3625.628	8	27573.60	$a^4F_{3\frac{1}{2}}-z^2F^o_{3\frac{1}{2}}$	6	76	(188)	1031	1.069	0.993
3617.038	4d	27639.08	$a^2H_{4\frac{1}{2}}-y^4D^o_{3\frac{1}{2}}$	4	240	(100)	174	1.010	1.250
3616.701	4	27641.65	$a^2P_{1\frac{1}{2}}-z^4P^o_{\frac{1}{2}}$						
3615.133	10	27653.64	$a^4F_{3\frac{1}{2}}-y^2F^o_{3\frac{1}{2}}$	6	60	(212)	1180	(1.232)	1.172
3613.779	5	27664.00	$a^4F_{3\frac{1}{2}}-v^2D^o_{2\frac{1}{2}}$						
3610.794	8	27686.87	$b^4F_{2\frac{1}{2}}-y^2F^o_{2\frac{1}{2}}$	7b	—	(0)	1174	1.174	1.174
3609.447	12	27697.20	$b^4F_{2\frac{1}{2}}-v^2D^o_{2\frac{1}{2}}$	6	42	(104)	1139	1.160	1.118
3600.826	3	27763.51	$b^4P_{\frac{1}{2}}-z^4S^o_{1\frac{1}{2}}$						
3594.116	5	27815.35	$b^4F_{3\frac{1}{2}}-w^2D^o_{1\frac{1}{2}}$	5	271	(129)	—	(1.163)	0.892
3591.065	2	27838.98	$a^2F_{2\frac{1}{2}}-t^2D^o_{1\frac{1}{2}}$	4	196	(98)	606	0.984	1.180
3588.237	2	27860.53	$b^4F_{1\frac{1}{2}}-v^2P^o_{1\frac{1}{2}}$						
3579.343	4	27930.14	$b^2D_{1\frac{1}{2}}-y^4F^o_{1\frac{1}{2}}$	6	133	(203)	898	0.965	0.832
3573.511	3	27975.73	$a^2F_{3\frac{1}{2}}-t^2P^o_{1\frac{1}{2}}$						
3573.222	5	27977.99	$a^2F_{2\frac{1}{2}}-z^4G^o_{3\frac{1}{2}}$	5	154	(76)	1523	0.987	1.141
3572.399	8	27984.43	$b^2D_{1\frac{1}{2}}-t^2D^o_{1\frac{1}{2}}$	6	212	(321)	1075	0.967	1.179
3563.93	2	28050.93	$b^4P_{1\frac{1}{2}}-y^4P^o_{1\frac{1}{2}}$						
3559.958	6	28082.23	$a^2F_{3\frac{1}{2}}-z^4G^o_{2\frac{1}{2}}$						
3559.456	10	28086.19	$a^4P_{\frac{1}{2}}-z^4P^o_{\frac{1}{2}}$	6	615	(308)	1810	2.118	1.503
3553.379	4	28134.22	$a^2G_{4\frac{1}{2}}-y^4F^o_{3\frac{1}{2}}$	4	215	(115)	—	0.943	1.158
3551.870	2d	28146.17	$b^4P_{1\frac{1}{2}}-z^4D^o_{2\frac{1}{2}}$	4	395	(192)	619	1.607	1.212
3545.290	5	28198.41	$a^4F_{3\frac{1}{2}}-w^2P^o_{1\frac{1}{2}}$						
3541.622	8	28227.61	$b^2D_{4\frac{1}{2}}-z^4G^o_{3\frac{1}{2}}$	5	—	—	1145	(0.968)	1.037
3539.589	8	28243.83	$a^4F_{1\frac{1}{2}}-z^4F^o_{2\frac{1}{2}}$	5	284	(140)	1346	0.636	0.920
3523.557	5wh	28372.33	$a^4P_{1\frac{1}{2}}-y^4F^o_{1\frac{1}{2}}$						
3516.827	—	28426.62	$a^4P_{1\frac{1}{2}}-t^2D^o_{1\frac{1}{2}}$	6	425	(636)	1395	1.608	1.183
3514.529	8	28445.21	$b^2D_{2\frac{1}{2}}-y^4F^o_{2\frac{1}{2}}$	6	133	(330)	1099	1.033	1.166
3506.854	6	28507.46	$b^4P_{1\frac{1}{2}}-y^4P^o_{\frac{1}{2}}$	4	624	(312)	1279	1.592	2.216
3502.783	8	28540.59	$a^4P_{2\frac{1}{2}}-y^4D^o_{1\frac{1}{2}}$	5	150	(71)	1657	1.426	1.276
3499.996	8	28563.32	$a^4P_{1\frac{1}{2}}-t^2P^o_{1\frac{1}{2}}$	6	498	(748)	1360	1.606	1.108
3493.526	30	28616.22	$a^2P_{\frac{1}{2}}-t^2D^o_{1\frac{1}{2}}$	4	—	—	1150	(1.254)	1.185
3486.976	5	28669.97	$b^2D_{1\frac{1}{2}}-y^4D^o_{\frac{1}{2}}$	5	—	—	1193	(0.968)	0.526
3482.763	—	28704.65	$b^4F_{1\frac{1}{2}}-z^2P^o_{\frac{1}{2}}$	7b	—	(0)	590	(0.586)	0.57
3476.917	5	28752.91	$a^2P_{\frac{1}{2}}-t^2P^o_{1\frac{1}{2}}$						
3473.455	—	28781.77	$a^2G_{4\frac{1}{2}}-r^2D^o_{3\frac{1}{2}}$	4	261	—	301	0.952	1.213
3473.033	10	28785.06	$a^4P_{2\frac{1}{2}}-y^4F^o_{2\frac{1}{2}}$	6	254	(636)	1282	1.418	1.164
3469.926	12	28810.84	$a^4F_{4\frac{1}{2}}-z^4F^o_{3\frac{1}{2}}$	6	160	(558)	1153	1.232	1.072
3465.929	5	28844.06	$b^4F_{3\frac{1}{2}}-z^4F^o_{3\frac{1}{2}}$						
3463.722	10	28862.44	$a^2D_{2\frac{1}{2}}-z^4S^o_{1\frac{1}{2}}$	4	212	(106)	926	1.242	1.454
3462.855	10	28869.67	$a^2G_{4\frac{1}{2}}-u^2F^o_{3\frac{1}{2}}$	4	153	(77)	569	0.950	1.103
3454.657	3d	28938.17	$b^4P_{\frac{1}{2}}-y^4P^o_{1\frac{1}{2}}$						
3452.683	10	28954.72	$a^4P_{\frac{1}{2}}-w^2P^o_{\frac{1}{2}}$	6	1147	(574)	1542	2.116	0.969
3450.949	8	28969.27	$a^2D_{2\frac{1}{2}}-y^4D^o_{2\frac{1}{2}}$	6	83	(182)	1240	(1.245)	1.162
3443.124	6	29035.10	$b^2D_{2\frac{1}{2}}-z^4P^o_{1\frac{1}{2}}$	4	388	(193)	463	1.037	1.425
3438.953	10	29070.32	$b^4F_{4\frac{1}{2}}-z^4F^o_{4\frac{1}{2}}$	6	80	(358)	1215	1.255	1.175
3435.979	12	29095.48	$a^4F_{1\frac{1}{2}}-z^2F^o_{2\frac{1}{2}}$	5	356	(179)	1536	0.643	0.999
3434.000	12	29112.24	$b^4F_{1\frac{1}{2}}-z^4D^o_{2\frac{1}{2}}$	5	630	(313)	2167	0.591	1.221
3430.558	5	29141.45	$b^2D_{1\frac{1}{2}}-y^4D^o_{1\frac{1}{2}}$						
3427.466	2	29167.74	$a^2D_{2\frac{1}{2}}-x^4D^o_{1\frac{1}{2}}$						
3425.948	5	29180.66	$b^2D_{2\frac{1}{2}}-w^2F^o_{2\frac{1}{2}}$	6	70	(174)	1068	1.033	1.103
3422.657	3	29208.72	$a^4F_{4\frac{1}{2}}-w^2F^o_{3\frac{1}{2}}$						
3418.782	6	29241.83	$b^4F_{3\frac{1}{2}}-w^2F^o_{2\frac{1}{2}}$						
3417.12	3	29256.05	$b^2D_{1\frac{1}{2}}-t^2P^o_{\frac{1}{2}}$						
3411.789	6	29301.76	$a^2P_{\frac{1}{2}}-y^4D^o_{\frac{1}{2}}$	6	738	(369)	887	1.256	0.518
3403.275	3d	29375.06	$a^4P_{2\frac{1}{2}}-z^4P^o_{1\frac{1}{2}}$	7b	—	(0)	1424	1.424	1.424
3402.031	5	29385.80	$b^2D_{1\frac{1}{2}}-y^4F^o_{2\frac{1}{2}}$	5	195	(91)	—	(0.968)	1.163
3401.649	4	29389.11	$a^2D_{1\frac{1}{2}}-y^4F^o_{1\frac{1}{2}}$						
3401.03	1d	29394.45	$b^4P_{\frac{1}{2}}-y^4P^o_{\frac{1}{2}}$						
3395.381	4	29443.36	$a^2D_{1\frac{1}{2}}-t^2D^o_{1\frac{1}{2}}$	6	376	(564)	—	(0.800)	1.176
3392.040	10	29472.35	$a^4F_{2\frac{1}{2}}-y^2G^o_{3\frac{1}{2}}$	5	124	(64)	1505	1.071	1.195
3389.645	6	29493.18	$b^4F_{1\frac{1}{2}}-z^4D^o_{1\frac{1}{2}}$	6	274	(412)	719	0.582	0.856
3386.504	6	29520.53	$a^4P_{2\frac{1}{2}}-u^2F^o_{2\frac{1}{2}}$	6	312	(780)	1263	1.420	1.108
3379.674	4	29580.19	$a^2D_{1\frac{1}{2}}-u^2F^o_{2\frac{1}{2}}$						
3378.579	6	29589.78	$a^4P_{1\frac{1}{2}}-z^2S^o_{\frac{1}{2}}$	4	631	(316)	1292	1.607	2.238
3366.526	5	29695.71	$b^4F_{4\frac{1}{2}}-y^4D^o_{3\frac{1}{2}}$	7b	—	(0)	1253	1.253	1.253
3363.737	2d	29720.33	$a^4F_{1\frac{1}{2}}-v^2P^o_{1\frac{1}{2}}$						
3362.533	3	29730.97	$a^2G_{4\frac{1}{2}}-x^2G^o_{4\frac{1}{2}}$						
3358.606	10	29765.73	$b^4F_{1\frac{1}{2}}-z^4D^o_{\frac{1}{2}}$	5	242	(121)	706	0.585	0.343
3357.049	4	29779.54	$a^2P_{\frac{1}{2}}-z^2S^o_{\frac{1}{2}}$						
3351.599	4	29827.96	$a^4P_{1\frac{1}{2}}-y^4F^o_{2\frac{1}{2}}$						
3351.230	10	29831.25	$a^4F_{2\frac{1}{2}}-z^4D^o_{1\frac{1}{2}}$	5	210	(107)	1389	1.076	0.866
3344.882	8	29887.86	$a^2F_{2\frac{1}{2}}-r^2D^o_{2\frac{1}{2}}$						
3344.882	8	29887.86	$a^2P_{\frac{1}{2}}-v^2P^o_{\frac{1}{2}}$						
3337.869	12	29950.64	$b^4F_{1\frac{1}{2}}-v^2D^o_{2\frac{1}{2}}$	5	532	(266)	1908	0.580	1.112
3335.062	8	29975.86	$b^2D_{1\frac{1}{2}}-z^4P^o_{1\frac{1}{2}}$						

TABLE I.—*Continued.*

Wave-length	Arc int.	Wave number	Classification	Type	Sep.	p	n	g_1	g_2
3335.062	8	29975.86	$a^2F_{3\frac{1}{2}}-u^2F^\circ_{3\frac{1}{2}}$						
3334.605	10	29979.97	$a^4F_{4\frac{1}{2}}-z^4G^\circ_{4\frac{1}{2}}$	6	163	(730)	1228	1.311	1.148
3334.058	2*d*	29981.89	$b^4P_{1\frac{1}{2}}-y^4F^\circ_{2\frac{1}{2}}$						
3332.395	5	29999.85	$a^2P_{1\frac{1}{2}}-y^4D^\circ_{2\frac{1}{2}}$	5	196	(102)	1469	0.977	1.173
3328.25	4	30037.21	$a^2D_{2\frac{1}{2}}-y^4F^\circ_{1\frac{1}{2}}$	4	316	(159)	763	1.240	1.556
3325.132	10	30065.38	$a^4F_{3\frac{1}{2}}-s^2D^\circ_{2\frac{1}{2}}$	5	—	—	1400	(1.232)	1.166
3324.754	10	30068.79	$b^4F_{1\frac{1}{2}}-u^2D^\circ_{1\frac{1}{2}}$	6	304	(457)	732	0.579	0.883
3321.453	10	30098.68	$b^4F_{2\frac{1}{2}}-s^2D^\circ_{2\frac{1}{2}}$	7b	—	(0)	1152	1.152	1.152
3317.75	6	30132.27	$a^2D_{2\frac{1}{2}}-x^4D^\circ_{2\frac{1}{2}}$	6	38	(96)	1.223	1.242	1.204
3316.23	5	30146.08	$a^4P_{\frac{1}{2}}-y^4F^\circ_{1\frac{1}{2}}$	4	1286	(643)	187	2.116	0.830
3312.08	3	30183.85	$a^2H_{4\frac{1}{2}}-y^2H^\circ_{4\frac{1}{2}}$						
3310.52	3*d*	30198.07	$a^2P_{1\frac{1}{2}}-x^4D^\circ_{1\frac{1}{2}}$						
3310.249	8	30200.55	$a^4P_{\frac{1}{2}}-t^2D^\circ_{1\frac{1}{2}}$	4	908	(454)	714	2.08	1.17
3300.613	5	30288.71	$a^4F_{2\frac{1}{2}}-v^2D^\circ_{2\frac{1}{2}}$						
3295.529	10	30335.44	$a^4P_{2\frac{1}{2}}-x^4D^\circ_{2\frac{1}{2}}$						
3295.320	10	30337.36	$a^4P_{\frac{1}{2}}-t^2P^\circ_{1\frac{1}{2}}$						
3291.743	10	30370.33	$a^4F_{4\frac{1}{2}}-z^4G^\circ_{3\frac{1}{2}}$	5	172	(89)	1913	1.311	1.139
3287.787	—	30406.86	$a^4F_{2\frac{1}{2}}-u^2D^\circ_{1\frac{1}{2}}$	5	178	(91)	1342	1.083	0.905
3286.577	10	30418.06	$a^4P_{1\frac{1}{2}}-z^4P^\circ_{1\frac{1}{2}}$	6	197	(296)	1510	1.612	1.415
3280.374	10	30475.58	$a^4P_{1\frac{1}{2}}-r^2D^\circ_{2\frac{1}{2}}$						
3270.816	8	30564.63	$a^4F_{1\frac{1}{2}}-z^2P^\circ_{\frac{1}{2}}$	—	—	—	676	(0.639)	0.575
3267.002	10	30600.31	$a^2D_{1\frac{1}{2}}-y^2D^\circ_{1\frac{1}{2}}$	6	467	(701)	1039	0.796	1.263
3266.3*e*2	4	30606.49	$a^2D_{1\frac{1}{2}}-z^2S^\circ_{\frac{1}{2}}$						
3254.811	8	30714.92	$a^2D_{1\frac{1}{2}}-v^2P^\circ_{\frac{1}{2}}$	5	—	—	83	(0.800)	0.74
3245.760	12	30800.57	$a^4P_{2\frac{1}{2}}-z^4P^\circ_{2\frac{1}{2}}$	6	247	(620)	1295	1.419	1.172
3241.112	10	30844.74	$a^2D_{1\frac{1}{2}}-y^4F^\circ_{2\frac{1}{2}}$	5	367	(181)	1717	0.801	1.168
3233.334	8	30918.93	$b^4P_{1\frac{1}{2}}-s^2F^\circ_{2\frac{1}{2}}$	4	439	—	489	1.589	1.150
3230.869	15	30942.52	$a^2G_{3\frac{1}{2}}-t^2F^\circ_{2\frac{1}{2}}$	7b	—	(0)	970	(0.953)	0.944
3227.767	10	30972.26	$a^4F_{1\frac{1}{2}}-z^4D^\circ_{\frac{1}{2}}$	5	576	(293)	2064	0.641	1.217
3225.359	12	30995.38	$a^2G_{3\frac{1}{2}}-y^4F^\circ_{2\frac{1}{2}}$	6	116	(405)	1012	0.952	1.068
3223.803	6	31010.34	$a^4F_{4\frac{1}{2}}-v^2F^\circ_{3\frac{1}{2}}$	—	157	(80)	—	(1.232)	1.075
3220.348	—	31043.61	$b^4F_{2\frac{1}{2}}-v^2F^\circ_{2\frac{1}{2}}$	6	76	(191)	1140	(1.163)	1.087
3218.313	8	31063.24	$a^2H_{4\frac{1}{2}}-y^4F^\circ_{4\frac{1}{2}}$?						
3217.856	6	31067.65	$a^2P_{1\frac{1}{2}}-y^4P^\circ_{1\frac{1}{2}}$						
3217.457	10	31071.50	$b^2D_{2\frac{1}{2}}-s^2D^\circ_{1\frac{1}{2}}$	4	212	(104)	704	1.020	1.232
3208.025	18	31162.84	$a^2P_{1\frac{1}{2}}-x^4D^\circ_{2\frac{1}{2}}$	5	220	(112)	1534	0.993	1.213
3197.702	9	31253.68	$b^2D_{2\frac{1}{2}}-t^2F^\circ_{3\frac{1}{2}}$						
3193.311	6	31306.44	$b^2D_{2\frac{1}{2}}-y^4F^\circ_{2\frac{1}{2}}$	5	—	(0)	1136	(1.034)	1.062
3191.095	5	31328.18	$a^4F_{2\frac{1}{2}}-u^2D^\circ_{2\frac{1}{2}}$						
3188.281	—	31355.84	$b^4F_{1\frac{1}{2}}-u^2P^\circ_{1\frac{1}{2}}$	6	451	(677)	814	0.588	1.039
3183.794	8	31400.02	$a^2D_{2\frac{1}{2}}-z^2F^\circ_{2\frac{1}{2}}$	7b	—	(0)	1230	1.230	1.230
3182.648	10	31411.32	$a^4P_{2\frac{1}{2}}-s^2D^\circ_{1\frac{1}{2}}$	5	169	(85)	1667	1.423	1.254
3180.199	15	31435.51	$a^4F_{3\frac{1}{2}}-z^4F^\circ_{3\frac{1}{2}}$	7b	—	(0)	1074	1.074	1.074
3176.507	10	31472.05	$a^4P_{\frac{1}{2}}-v^2P^\circ_{\frac{1}{2}}$	6	1422	(711)	1405	2.116	0.694
3174.460	8	31492.32	$a^2D_{1\frac{1}{2}}-r^2D^\circ_{2\frac{1}{2}}$	—	414	(207)	—	(0.800)	1.214
3174.166	10	31495.26	$b^4F_{1\frac{1}{2}}-u^2F^\circ_{2\frac{1}{2}}$	5	362	(181)	1503	0.597	0.959
3169.279	12	31543.82	$a^4F_{4\frac{1}{2}}-x^2G^\circ_{3\frac{1}{2}}$	5	200	(100)	2014	1.320	1.120
3165.628	—	31580.20	$a^2D_{1\frac{1}{2}}-u^2F^\circ_{2\frac{1}{2}}$						
3161.071	5	31625.72	$a^4F_{1\frac{1}{2}}-x^4D^\circ_{\frac{1}{2}}$						
3159.013	—	31646.32	$a^4P_{2\frac{1}{2}}-y^4F^\circ_{3\frac{1}{2}}$	4	343	(173)	207	1.402	1.059
3154.26	15	31694.01	$a^4F_{2\frac{1}{2}}-u^2P^\circ_{1\frac{1}{2}}$	7b	—	(0)	1101	(1.076)	1.060
3137.174	10	31866.62	$a^2F_{2\frac{1}{2}}-s^2D^\circ_{1\frac{1}{2}}$	4	262	(130)	586	0.983	1.245
3131.070	12	31928.74	$a^4F_{1\frac{1}{2}}-u^2D^\circ_{1\frac{1}{2}}$	6	250	(381)	763	0.639	0.889
3119.484	15	32047.32	$a^4F_{3\frac{1}{2}}-z^4G^\circ_{4\frac{1}{2}}$	4	—	—	907	(1.232)	1.159
3114.208	10	32101.61	$a^2F_{2\frac{1}{2}}-y^4F^\circ_{2\frac{1}{2}}$	5	—	—	1255	(0.986)	1.062
3105.477	10	32191.86	$a^4P_{\frac{1}{2}}-z^4P^\circ_{1\frac{1}{2}}$	—	—	—	1077	(2.112)	1.422
3097.270	10	32277.16	$b^4F_{2\frac{1}{2}}-y^4F^\circ_{1\frac{1}{2}}$	5	330	(168)	1649	1.160	0.830
3090.102	15	32352.03	$b^4F_{1\frac{1}{2}}-s^2D^\circ_{2\frac{1}{2}}$	5	564	(279)	1984	0.581	1.145
3088.842	10	32365.22	$b^2D_{1\frac{1}{2}}-x^4D^\circ_{\frac{1}{2}}$						
3081.982	—	32437.26	$a^4F_{3\frac{1}{2}}-z^4G^\circ_{3\frac{1}{2}}$	6	91	(318)	—	(1.232)	1.141
3081.662	10	32440.63	$b^4F_{4\frac{1}{2}}-x^4D^\circ_{3\frac{1}{2}}$	7b	—	—	1212	(1.242)	1.254
3078.832	10	32470.45	$b^4F_{3\frac{1}{2}}-z^4G^\circ_{3\frac{1}{2}}$	7b	—	—	1104	(1.163)	1.146
3072.120	10	32541.39	$a^4F_{3\frac{1}{2}}-z^4G^\circ_{3\frac{1}{2}}$	5	184	(93)	1699	1.243	1.059
3068.987	12	32574.60	$b^4F_{2\frac{1}{2}}-z^4G^\circ_{2\frac{1}{2}}$	6	110	(276)	1123	1.178	1.068
3066.420	10	32601.87	$a^2P_{1\frac{1}{2}}-q^2D^\circ_{2\frac{1}{2}}$	7b	—	(0)	1020	(0.977)	0.993
3065.935	12	32607.03	$a^2G_{4\frac{1}{2}}-z^4F^\circ_{4\frac{1}{2}}$						
3058.142	8	32690.12	$a^4F_{2\frac{1}{2}}-s^2D^\circ_{2\frac{1}{2}}$						
3056.099	10	32711.97	$b^2D_{2\frac{1}{2}}-z^4S^\circ_{1\frac{1}{2}}$	4	434	—	387	1.038	1.472
3043.249	10	32850.09	$a^4F_{1\frac{1}{2}}-u^2D^\circ_{2\frac{1}{2}}$	5	458	—	—	0.62	1.08
3042.312	—	32860.21	$a^2D_{1\frac{1}{2}}-z^4P^\circ_{2\frac{1}{2}}$	—	372	(185)	—	(0.800)	1.172
3035.542	10	32933.49	$a^4F_{1\frac{1}{2}}-t^2D^\circ_{2\frac{1}{2}}$	5	489	(243)	—	0.61	1.10
3024.669	10	33051.87	$a^4P_{2\frac{1}{2}}-z^4S^\circ_{1\frac{1}{2}}$	4?	—	—	1382	(1.419)	1.444
3018.51	15	33119.31	$b^4F_{4\frac{1}{2}}-y^4F^\circ_{4\frac{1}{2}}$	6	156	(691)	1164	1.257	1.101
3014.925	12	33158.69	$a^4P_{2\frac{1}{2}}-y^4D^\circ_{2\frac{1}{2}}$	6	254	(626)	1296	1.429	1.175
3012.708	12	33183.09	$a^4F_{4\frac{1}{2}}-z^4D^\circ_{3\frac{1}{2}}$	5	180	(92)	1944	1.317	1.137
3009.725	15	33215.98	$a^4F_{1\frac{1}{2}}-u^2P^\circ_{1\frac{1}{2}}$	6	398	(596)	835	0.638	1.036
3008.491	15	33229.60	$a^4F_{4\frac{1}{2}}-x^2G^\circ_{4\frac{1}{2}}$	6	177	(791)	1250	1.310	1.133
3008.22	2	33232.59	$a^2G_{3\frac{1}{2}}-y^4D^\circ_{2\frac{1}{2}}$						
3002.39	15	33297.12	$b^4F_{1\frac{1}{2}}-v^2F^\circ_{2\frac{1}{2}}$	5	495	(248)	1826	0.585	1.080
2997.15	10	33355.33	$a^4F_{1\frac{1}{2}}-u^2F^\circ_{2\frac{1}{2}}$	5	320	(160)	1418	(0.639)	0.951
2996.980	10	33357.22	$a^4P_{2\frac{1}{2}}-x^4D^\circ_{1\frac{1}{2}}$	5	100	(50)	1576	1.43	1.33
2993.803	12	33392.62	$a^4F_{4\frac{1}{2}}-z^4G^\circ_{4\frac{1}{2}}$	4	—	(0)	1022	(1.312)	1.259
2986.788	12	33471.05	$a^2D_{1\frac{1}{2}}-s^2D^\circ_{1\frac{1}{2}}$	6	450	(675)	1026	0.804	1.254
2985.246	15	33488.34	$b^4F_{3\frac{1}{2}}-y^4D^\circ_{2\frac{1}{2}}$	4	120	(60)	1035	1.18	1.30
2980.338	15	33543.48	$b^2D_{2\frac{1}{2}}-y^4D^\circ_{2\frac{1}{2}}$	5	210	(106)	1784	1.045	1.255
2972.224	4	33635.05	$a^4F_{2\frac{1}{2}}-v^2F^\circ_{2\frac{1}{2}}$	7b	—	(0)	1068	1.068	1.068
2971.439	—	33643.93	$b^4F_{3\frac{1}{2}}-z^2G^\circ_{3\frac{1}{2}}$	4?	—	—	1040	(1.163)	1.127
2969.069	2	33670.79	$a^2G_{3\frac{1}{2}}-x^4D^\circ_{2\frac{1}{2}}$						
2963.609	6	33732.82	$b^4F_{2\frac{1}{2}}-y^4F^\circ_{2\frac{1}{2}}$	7b	—	(0)	1165	1.165	1.165
2956.638	—	33812.34	$a^2F_{2\frac{1}{2}}-x^4D^\circ_{1\frac{1}{2}}$	4	319	(160)	504	0.983	1.302
2955.605	6	33824.16	$a^2D_{1\frac{1}{2}}-x^4D^\circ_{\frac{1}{2}}$	5	538	(270)	1068	0.799	0.261
2950.442	8	33883.35	$a^4P_{2\frac{1}{2}}-y^4D^\circ_{3\frac{1}{2}}$	4	173	(89)	803	1.413	1.240
2941.899	—	33981.82	$b^2D_{2\frac{1}{2}}-x^4D^\circ_{2\frac{1}{2}}$	6	172	(416)	—	(1.034)	1.206
2932.148	—	34094.74	$a^4P_{1\frac{1}{2}}-z^4S^\circ_{1\frac{1}{2}}$	6	137	(205)	—	(1.608)	1.471
2922.990	5	34201.56	$a^4P_{1\frac{1}{2}}-y^4D^\circ_{2\frac{1}{2}}$	4	443	—	—	1.616	1.173
2922.801	5	34203.77	$a^2P_{1\frac{1}{2}}-t^2P^\circ_{1\frac{1}{2}}$						
2912.760	5	34321.68	$a^4P_{2\frac{1}{2}}-z^4D^\circ_{2\frac{1}{2}}$	6	218	(545)	1314	1.425	1.207
2912.664	5	34322.81	$b^4F_{2\frac{1}{2}}-z^4P^\circ_{1\frac{1}{2}}$						
2912.012	8	34330.49	$a^4F_{1\frac{1}{2}}-x^4P^\circ_{\frac{1}{2}}$	4	862	(431)	205	0.630	1.492
2911.324	8	34338.60	$a^2F_{3\frac{1}{2}}-y^4D^\circ_{3\frac{1}{2}}$	5	261	(129)	—	(0.986)	1.247
2910.597	12*s*	34347.18	$a^4F_{3\frac{1}{2}}-r^2D^\circ_{2\frac{1}{2}}$	7b?	—	—	1251	(1.232)	1 222
2906.126	8	34400.02	$a^4P_{1\frac{1}{2}}-x^4D^\circ_{1\frac{1}{2}}$						
2903.170	6	34435.04	$a^4F_{3\frac{1}{2}}-u^2F^\circ_{2\frac{1}{2}}$						
2895.143	10	34530.51	$b^4F_{1\frac{1}{2}}-y^4F^\circ_{1\frac{1}{2}}$	6	240	(369)	703	0.582	0.822
2890.893	6	34581.27	$a^4P^\circ_{\frac{1}{2}}-x^4D^\circ_{\frac{1}{2}}$						
2882.516	8	34681.77	$a^2F_{2\frac{1}{2}}-y^4P^\circ_{1\frac{1}{2}}$	4	582	(291)	109	0.985	1.567
2879.205	10	34721.65	$b^4F_{1\frac{1}{2}}-t^2P^\circ_{1\frac{1}{2}}$	5	521	(789)	848	0.586	1.107
2874.630	—	34776.91	$a^2F_{3\frac{1}{2}}-z^4D^\circ_{2\frac{1}{2}}$	6	219	(540)	1099	0.989	1.208
2870.413	18	34827.99	$b^4F_{1\frac{1}{2}}-z^4G^\circ_{2\frac{1}{2}}$	5	460	(228)	1736	0.583	1.043
2861.338	—	34938.57	$a^2G_{3\frac{1}{2}}-z^2F^\circ_{3\frac{1}{2}}$	6	281	(986)	1096	0 951	1.232
2851.445	5*d*	35059.66	$a^4F_{3\frac{1}{2}}-t^2P^\circ_{1\frac{1}{2}}$	7b?	—	—	1030	(1.076)	1.107
2851.261	10*d*	35061.92	$a^4F_{3\frac{1}{2}}-z^4G^\circ_{3\frac{1}{2}}$	5	—	—	1254	(1.076)	1.127
2847.358	10	35109.98	$a^2G_{4\frac{1}{2}}-q^2D^\circ_{3\frac{1}{2}}$						
2842.815	12	35166.09	$a^4F_{2\frac{1}{2}}-z^4G^\circ_{3\frac{1}{2}}$	7b	—	—	1054	1.05	1.05
2840.156	8	35199.01	$a^4F_{1\frac{1}{2}}-w^2P^\circ_{\frac{1}{2}}$	4	330	(161)	473	0.640	0.970
2836.049	10	35249.98	$a^4F_{3\frac{1}{2}}-z^4D^\circ_{3\frac{1}{2}}$	6	99	(346)	1170	1.22	1.12
2834.484	7	35269.44	$a^4P_{1\frac{1}{2}}-y^4P^\circ_{1\frac{1}{2}}$	6	40	(50)	1581	1.60	1.56
2833.339	8	35283.69	$b^2D_{1\frac{1}{2}}-y^4P^\circ_{\frac{1}{2}}$	4	1263	(62)	343	0.975	2.238
2832.319	18	35296.40	$a^4F_{3\frac{1}{2}}-z^2G^\circ_{4\frac{1}{2}}$	4	—	—	832	(1.232)	1.142
2826.858	12	35364.58	$a^4P_{1\frac{1}{2}}-x^4D^\circ_{2\frac{1}{2}}$	4	404	(203)	591	1.605	1.201
2822.362	4*d*	35420.91	$b^2D_{2\frac{1}{2}}-q^2D^\circ_{2\frac{1}{2}}$						
2819.329	12	35459.02	$a^2P_{\frac{1}{2}}-y^4P^\circ_{1\frac{1}{2}}$	5	300	(155)	1694	1.246	1.546
2808.996	—	35589.44	$a^4P_{2\frac{1}{2}}-z^2F^\circ_{2\frac{1}{2}}$	4	190	(100)	798	(1.419)	1.242
2799.120	5	35715.01	$a^4F_{3\frac{1}{2}}-x^4P^\circ_{2\frac{1}{2}}$	7b	—	—	1288	(1.232)	1.211
2798.270	—	35725.87	$a^4P_{1\frac{1}{2}}-y^4P^\circ_{\frac{1}{2}}$	—	609	(305)	1302	1.607	2.216
2797.026	8	35741.74	$b^4F_{1\frac{1}{2}}-y^4D^\circ_{1\frac{1}{2}}$	6	683	(1019)	933	0.582	1.265
2794.260	10	35777.12	$a^2G_{4\frac{1}{2}}-y^2H^\circ_{4\frac{1}{2}}$	5	133	(69)	1553	0.965	1.098
2787.132	8	35868.62	$a^4P_{\frac{1}{2}}-z^4S^\circ_{1\frac{1}{2}}$	4	646	(328)	1136	2.100	1.454
2783.496	6	35915.47	$a^2P_{\frac{1}{2}}-y^4P^\circ_{\frac{1}{2}}$	6	958	(479)	1730	1.251	2.209
2778.710	10	35977.33	$a^2G_{3\frac{1}{2}}-x^4D^\circ_{2\frac{1}{2}}$	6	310	(1085)	1089	0.947	1.257
2778.027	3	35986.17	$b^4F_{1\frac{1}{2}}-y^4F^\circ_{2\frac{1}{2}}$						
2773.960	6	36038.93	$a^2D_{2\frac{1}{2}}-p^2D^\circ_{2\frac{1}{2}}$	6	—	—	1231	1.231	1.231
2770.822	10	36079.74	$a^4F_{2\frac{1}{2}}-y^4D^\circ_{1\frac{1}{2}}$	4	188	(101)	785	1.064	1.252
2768.848	15	36105.46	$a^4F_{4\frac{1}{2}}-z^4F^\circ_{4\frac{1}{2}}$	6	147	(661)	1240	1.314	1.167
2764.643	8	36160.37	$a^4P_{2\frac{1}{2}}-y^4P^\circ_{2\frac{1}{2}}$	6	68	(171)	1389	1.423	1.355
2763.613	10	36173.85	$a^4P_{\frac{1}{2}}-x^4D^\circ_{1\frac{1}{2}}$	4	794	(397)	916	2.107	1.313

TABLE I.—*Continued.*

Wave-length	Arc int.	Wave number	Classification	Type	Sep.	p	n	g_1	g_2
2760.396	5	36216.01	$a^2F_{2\frac{1}{2}}-q^2D^o_{2\frac{1}{2}}$	7b	—	(0)	988	0.988	0.988
2752.172	15	36324.22	$a^4F_{2\frac{1}{2}}-y^4F^o_{2\frac{1}{2}}$	6	82	(205)	1113	1.072	1.154
2749.542	10	36358.96	$b^4F_{2\frac{1}{2}}-s^2D^o_{1\frac{1}{2}}$	4	—	—	1059	(1.163)	1.234
2749.357	3	36361.41	$b^2D_{1\frac{1}{2}}-q^2D^o_{2\frac{1}{2}}$						
2747.853	6	36381.31	$a^2D_{1\frac{1}{2}}-z^4D^o_{2\frac{1}{2}}$	5	403	(209)	—	(0.800)	1.203
2747.161	10d	36390.47	$a^4F_{1\frac{1}{2}}-y^4F^o_{1\frac{1}{2}}$	6	188	(285)	731	0.636	0.824
2743.067	12	36444.78	$a^4F_{1\frac{1}{2}}-t^2D^o_{1\frac{1}{2}}$	6	543	(813)	899	0.628	1.171
2738.319	—	36507.97	$a^4F_{2\frac{1}{2}}-t^2F^o_{2\frac{1}{2}}$	5	291	(143)	1940	1.238	0.947
2735.830	—	36541.18	$b^4F_{2\frac{1}{2}}-t^2F^o_{2\frac{1}{2}}$	6	222	(542)	—	(1.163)	0.941
2734.354	10	36560.91	$a^4F_{2\frac{1}{2}}-y^4F^o_{2\frac{1}{2}}$	6	159	(555)	1152	1.240	1.081
2732.815	10	36581.50	$a^4F_{1\frac{1}{2}}-t^2P^o_{1\frac{1}{2}}$	6	464	(704)	867	0.638	1.102
2730.267	8	36615.63	$a^2F_{2\frac{1}{2}}-y^4F^o_{2\frac{1}{2}}$	6	356	(891)	1166	0.999	1.355
2729.330	10	36628.20	$a^4P_{2\frac{1}{2}}-z^4D^o_{2\frac{1}{2}}$	4	158	(83)	871	1.424	1.266
2728.915	6	36633.77	$b^4F_{1\frac{1}{2}}-r^2D^o_{2\frac{1}{2}}$	5	639	(319)	2177	0.577	1.216
2727.24	2h	36656.27	$a^2G_{3\frac{1}{2}}-y^4F^o_{4\frac{1}{2}}$	5	135	(69)	1560	0.953	1.088
2724.886	10	36687.94	$a^4F_{1\frac{1}{2}}-z^4G^o_{2\frac{1}{2}}$	5	408	(204)	1656	0.642	1.050
2722.383	10	36721.80	$b^4F_{1\frac{1}{2}}-u^2F^o_{2\frac{1}{2}}$	5	520	(260)	1892	0.591	1.111
2721.697	10	36730.92	$a^4F_{4\frac{1}{2}}-y^4D^o_{3\frac{1}{2}}$	5	—	—	1483	(1.312)	1.263
2720.829	—	36742.64	$a^2D_{1\frac{1}{2}}-y^4F^o_{1\frac{1}{2}}$	4	1418	(709)	78	0.787	2.205
2719.939	8	36754.66	$b^2D_{2\frac{1}{2}}-s^2F^o_{2\frac{1}{2}}$	6	118	(296)	1089	1.031	1.149
2719.465	5	36761.07	$b^2D_{1\frac{1}{2}}-y^4P^o_{2\frac{1}{2}}$	5	377	(189)	1908	0.967	1.344
2716.318	10	36803.65	$a^4P_{1\frac{1}{2}}-q^2D^o_{2\frac{1}{2}}$	4	609	(300)	70	1.602	0.993
2708.181	10	36914.23	$a^4F_{2\frac{1}{2}}-z^4F^o_{1\frac{1}{2}}$	4	344	(174)	553	1.065	1.409
2703.962	15	36971.82	$a^4F_{2\frac{1}{2}}-r^2D^o_{2\frac{1}{2}}$	6	142	(356)	1155	1.084	1.226
2698.742	6	37043.33	$a^4P_{\frac{1}{2}}-y^4P^o_{1\frac{1}{2}}$	4	543	(272)	1291	2.105	1.562
2697.550	5	37059.70	$a^4F_{2\frac{1}{2}}-u^2F^o_{2\frac{1}{2}}$	6	24	(60)	1092	1.080	1.104
2696.836	2h	37069.51	$a^2P_{1\frac{1}{2}}-p^2D^o_{2\frac{1}{2}}$	5	233	(118)	1539	0.957	1.190
2695.822	4	37083.45	$a^2F_{2\frac{1}{2}}-z^4D^o_{2\frac{1}{2}}$	—	274	(132)	—	(0.986)	1.260
2692.422	20	37130.36	$a^4F_{1\frac{1}{2}}-y^4D^o_{\frac{1}{2}}$	5	—	—	690	(0.639)	0.537
2687.138	10	37203.29	$a^4P_{1\frac{1}{2}}-y^4P^o_{2\frac{1}{2}}$	4	260	(130)	953	1.596	1.336
2675.670	8	37362.73	$a^4P_{2\frac{1}{2}}-s^2P^o_{1\frac{1}{2}}$	5	294	(160)	1880	1.43	1.14
2665.892	—	37499.76	$a^4P_{\frac{1}{2}}-y^4P^o_{\frac{1}{2}}$	7b?	—	(0)	2168	(2.112)	2.224
2662.349	10	37549.66	$a^2F_{2\frac{1}{2}}-s^2F^o_{2\frac{1}{2}}$	6	165	(413)	1067	0.981	1.146
2658.667	15	37601.66	$a^4F_{1\frac{1}{2}}-y^4D^o_{1\frac{1}{2}}$	6	628	(938)	955	0.635	1.263
2652.073	6	37695.14	$b^2D_{1\frac{1}{2}}-s^2F^o_{2\frac{1}{2}}$	4	175	(92)	1428	0.991	1.166
2650.588	10	37716.26	$a^4F_{1\frac{1}{2}}-v^2P^o_{\frac{1}{2}}$	7b?	—	—	616	(0.639)	0.685
2643.29	5	37820.39	$a^2D_{1\frac{1}{2}}-q^2D^o_{2\frac{1}{2}}$	5	198	(99)	1291	0.803	1.001
2641.494	15	37846.10	$a^4F_{1\frac{1}{2}}-y^4F^o_{2\frac{1}{2}}$	5	525	(264)	1955	0.635	1.160
2639.508	8	37874.58	$a^4F_{2\frac{1}{2}}-z^4D^o_{2\frac{1}{2}}$						
2633.333	5	27963.38	$b^2D_{1\frac{1}{2}}-s^2F^o_{1\frac{1}{2}}$	6	140	(223)	—	(0.968)	1.117
2630.825	—	37999.57	$b^4F_{2\frac{1}{2}}-z^4S^o_{1\frac{1}{2}}$	4	298	(154)	717	1.164	1.462
2625.736	8	38073.22	$a^4F_{2\frac{1}{2}}-y^4D^o_{2\frac{1}{2}}$	5?	—	—	1332	(1.232)	1.194
2623.454	10	38106.33	$b^4F_{2\frac{1}{2}}-y^4D^o_{2\frac{1}{2}}$	7b	—	(0)	1163	1.163	1.163
2618.913	12	38172.40	$a^4F_{2\frac{1}{2}}-z^4F^o_{4\frac{1}{2}}$						
2609.555	10	38304.88	$b^4F_{2\frac{1}{2}}-x^4D^o_{1\frac{1}{2}}$	4	126	(63)	965	1.154	1.280
2607.482	4	38339.73	$a^4F_{2\frac{1}{2}}-s^4F^o_{2\frac{1}{2}}$	6	91	(227)	—	(1.076)	1.167
2603.011	—	38405.58	$a^4P_{1\frac{1}{2}}-s^2P^o_{1\frac{1}{2}}$	6	492	(738)	—	(1.608)	1.116
2600.885	15	38436.97	$a^4F_{4\frac{1}{2}}-z^2F^o_{3\frac{1}{2}}$	5	—	—	1519	(1.312)	1.253
2597.050	20	38493.73	$a^4F_{1\frac{1}{2}}-r^2D^o_{2\frac{1}{2}}$	5	574	(291)	2074	0.640	1.214
2590.224	—	38595.16	$a^2P_{\frac{1}{2}}-s^2P^o_{1\frac{1}{2}}$	7b?	134	(67)	1054	1.255	1.121
2589.063	20	38612.47	$b^4F_{1\frac{1}{2}}-s^2D^o_{1\frac{1}{2}}$	6	664	(993)	926	0.586	1.250
2576.907	—	38794.60	$b^4F_{1\frac{1}{2}}-t^2F^o_{2\frac{1}{2}}$	—	364	(182)	—	(0.586)	0.950
2576.690	15	38797.87	$a^4F_{2\frac{1}{2}}-y^4D^o_{2\frac{1}{2}}$	7b	—	(0)	1238	1.238	1.238
2574.484	10	38831.11	$b^4F_{2\frac{1}{2}}-y^4D^o_{1\frac{1}{2}}$	5	—	—	1409	(1.163)	1.233
2566.589	15	38950.55	$a^4F_{2\frac{1}{2}}-s^2D^o_{1\frac{1}{2}}$	4	168	(84)	814	1.066	1.234
2565.597	10	38965.61	$b^4F_{1\frac{1}{2}}-z^4D^o_{\frac{1}{2}}$	5	324	(162)	736	0.586	0.262
2553.242	—	39154.15	$a^2D_{1\frac{1}{2}}-s^2F^o_{2\frac{1}{2}}$	5	354	(183)	1686	0.804	1.158
2551.931	—	39174.27	$b^4F_{2\frac{1}{2}}-y^4P^o_{1\frac{1}{2}}$	4	400	(204)	551	1.152	1.552
2551.200	—	39185.49	$a^4F_{2\frac{1}{2}}-y^4F^o_{3\frac{1}{2}}$	7b	—	(0)	1073	1.073	1.073
2547.902	15	39236.21	$a^4F_{3\frac{1}{2}}-z^4D^o_{2\frac{1}{2}}$	5?	—	—	1280	(1.232)	1.21
2545.747	10	39269.42	$b^4F_{2\frac{1}{2}}-z^4D^o_{2\frac{1}{2}}$	6	29	(74)	1185	1.170	1.199
2545.345	15	39275.62	$a^4F_{4\frac{1}{2}}-y^4H^o_{4\frac{1}{2}}$	6	221	(994)	1205	1.312	1.091
2535.870	5	39422.36	$a^2D_{1\frac{1}{2}}-s^2P^o_{1\frac{1}{2}}$	6	328	(483)	—	(0.800)	1.128
2532.452	10	39475.56	$a^4F_{4\frac{1}{2}}-z^4D^o_{3\frac{1}{2}}$	7b?	—	—	1430	(1.312)	1.28
2525.931	8	39577.47	$a^2G_{3\frac{1}{2}}-p^2D^o_{2\frac{1}{2}}$	4	252	(128)	323	0.951	1.203
2507.92	8	39861.7	$a^4F_{4\frac{1}{2}}-z^4P^o_{2\frac{1}{2}}$	5	533	(266)	1973	0.639	1.172
2489.64	5	40154.3	$a^4F_{4\frac{1}{2}}-y^4F^o_{4\frac{1}{2}}$	6	223	(989)	1197	1.314	1.091
2485.058	—	40228.36	$a^4P_{2\frac{1}{2}}-p^2D^o_{2\frac{1}{2}}$	6	210	(534)	1322	1.429	1.219
2476.96	6	40359.9	$b^4F_{1\frac{1}{2}}-y^4D^o_{2\frac{1}{2}}$	5	1154	(578)	2045	0.614	1.468
2468.150	6	40503.93	$a^4F_{2\frac{1}{2}}-z^2F^o_{2\frac{1}{2}}$	7b	—	(0)	1236	1.236	1.236
2466.126	10	40537.17	$b^4F_{2\frac{1}{2}}-z^2F^o_{2\frac{1}{2}}$	5	—	—	1374	(1.163)	1.223
2464.844	—	40558.25	$b^4F_{1\frac{1}{2}}-z^4D^o_{1\frac{1}{2}}$	6	723	(1085)	—	0.590	1.313
2462.854	—	40591.02	$a^4F_{3\frac{1}{2}}-z^4S^o_{1\frac{1}{2}}$	4	388	(197)	511	1.083	1.471
2459.007	8	40654.52	$a^4F_{1\frac{1}{2}}-t^2F^o_{2\frac{1}{2}}$	5	300	(148)	1397	0.651	0.951
2457.751	—	40675.29	$a^4F_{2\frac{1}{2}}-q^2D^o_{2\frac{1}{2}}$	5	222	(113)	1784	1.237	1.015
2455.746	—	40708.50	$b^4F_{2\frac{1}{2}}-q^2D^o_{2\frac{1}{2}}$	6	160	(400)	—	(1.163)	1.003
2448.700	—	40825.58	$a^4F_{1\frac{1}{2}}-z^4D^o_{\frac{1}{2}}$	—	374	(187)	—	(0.639)	0.265
2444.469	5	40896.28	$a^4F_{2\frac{1}{2}}-z^4D^o_{1\frac{1}{2}}$	4	218	(101)	726	1.055	1.273
2413.405	5	41422.63	$a^4F_{2\frac{1}{2}}-y^4D^o_{2\frac{1}{2}}$						
2407.581	—	41522.82	$b^4F_{1\frac{1}{2}}-z^4D^o_{2\frac{1}{2}}$	—	615	(309)	—	(0.586)	1.201
2406.434	7	41542.65	$a^4F_{2\frac{1}{2}}-z^4D^o_{3\frac{1}{2}}$	6	—	—	1242	1.242	1.242
2404.510	30	41575.85	$b^4F_{2\frac{1}{2}}-z^4D^o_{2\frac{1}{2}}$	5	—	—	1475	(1.163)	1.252
2393.56	1	41766.0	$a^4F_{2\frac{1}{2}}-y^4P^o_{1\frac{1}{2}}$						
2388.143	4	41860.77	$a^4F_{3\frac{1}{2}}-z^4D^o_{3\frac{1}{2}}$	6	128	(320)	1141	1.077	1.205
2386.81	2	41884.1	$b^4F_{1\frac{1}{2}}-y^4P^o_{\frac{1}{2}}$	—	1636	(818)	—	(0.586)	2.222
2379.740	1	42008.58	$a^4F_{3\frac{1}{2}}-s^2F^o_{2\frac{1}{2}}$?						
2377.832	10	42042.27	$b^4F_{2\frac{1}{2}}-s^2F^o_{2\frac{1}{2}}$	7b	—	(0)	1157	1.157	1.157
2373.846	3	42112.86	$a^4F_{1\frac{1}{2}}-z^4S^o_{1\frac{1}{2}}$						
2367.821	1	42220.04	$a^4F_{1\frac{1}{2}}-y^4D^o_{2\frac{1}{2}}$						
2356.755	18	42418.25	$a^4F_{1\frac{1}{2}}-z^4D^o_{1\frac{1}{2}}$	6	668	(1003)	990	0.640	1.308
2326.922	6	42962.02	$b^4F_{1\frac{1}{2}}-q^2D^o_{2\frac{1}{2}}$	5	412	(206)	1618	0.591	1.003
2317.926	8	43128.73	$a^4F_{2\frac{1}{2}}-z^2F^o_{2\frac{1}{2}}$						
2309.396	2	43288.04	$a^4F_{1\frac{1}{2}}-y^4P^o_{1\frac{1}{2}}$						
2287.61	50	43700.0	$a^4F_{2\frac{1}{2}}-y^4P^o_{2\frac{1}{2}}$						
2285.28	2	43744.7	$a^4F_{1\frac{1}{2}}-y^4P^o_{\frac{1}{2}}$						
2263.40	12	44167.6	$a^4F_{3\frac{1}{2}}-z^4D^o_{2\frac{1}{2}}$						
2243.26	10	44564.1	$b^4F_{1\frac{1}{2}}-s^2P^o_{1\frac{1}{2}}$						
2239.757	18	44633.81	$a^4F_{2\frac{1}{2}}-s^2F^o_{2\frac{1}{2}}$	6	66	(164)	—	(1.076)	1.142
2230.35	35	44822.0	$a^4F_{1\frac{1}{2}}-q^2D^o_{2\frac{1}{2}}$	5	352	(180)	1531	0.651	1.003
2226.38	1	44902.0	$a^4F_{2\frac{1}{2}}-s^2P^o_{1\frac{1}{2}}$						
2212.87	6	45176.1	$b^4F_{2\frac{1}{2}}-p^2D^o_{2\frac{1}{2}}$						
2210.64	10	45221.6	$a^4F_{1\frac{1}{2}}-y^4P^o_{2\frac{1}{2}}$						
2153.37	10	46424.1	$a^4F_{1\frac{1}{2}}-s^2P^o_{1\frac{1}{2}}$						

magnet.[6] One part of thorium metal powder was mixed with five parts of silver powder and compressed to form handy electrodes of $\frac{1}{8}$-in. diameter. Light from the arc was taken transversely to the magnetic field, and was sent through a 50-mm Rochon prism formed from two quartz prisms separated by castor oil. In this way the component of parallel polarization p could be separated from that of perpendicular polarization n, the two being photographed simultaneously on two grating spectrographs having characteristics previously described.[6]

The magnetic field intensities used in the five sets of exposures were as follows: Z38L, 73,780 oersteds; Z38H, 93,160; Z56, 86,090; Z72p, 89,430; Z72s, 89,760. These field intensities were calculated from measured patterns of the *raies ultimes* of silver, calcium, and copper, and are believed to be correct to within ±0.3 percent.

[6] G. R. Harrison and F. Bitter, Phys. Rev. **57**, 15 (1940).

TABLE II. Th II classified lines, group B.

Wave-length	Arc int.	Wave number	Classification	Type	Sep.	p	n	g_1	g_2
6703.97	2	14912.42	$a^2D^\circ_{1\frac{1}{2}}-z^4G_{2\frac{1}{2}}$						
6616.89	2h	15108.68	$a^4D^\circ_{1\frac{1}{2}}-y^4F_{1\frac{1}{2}}$						
6560.02	5	15239.66	$2^\circ_{4\frac{1}{2}}-z^4H_{4\frac{1}{2}}$	6	237	(1063)	913	0.795	1.032
6503.57	5	15371.93	$a^2G^\circ_{3\frac{1}{2}}-z^4G_{2\frac{1}{2}}$	5	207	(104)	1501	0.985	0.778
6321.175	—	15815.48	$a^2D^\circ_{2\frac{1}{2}}-z^4G_{2\frac{1}{2}}$	6	313	(781)	—	(1.088)	0.775
6285.281	12	15905.80	$a^4D^\circ_{1\frac{1}{2}}-z^4F_{1\frac{1}{2}}$	5	374	(186)	816	0.254	0.628
6279.170	20	15921.28	$a^4D^\circ_{1\frac{1}{2}}-z^4F_{2\frac{1}{2}}$	4	178	(90)	719	1.165	0.987
6224.518	5	16061.07	$a^4D^\circ_{1\frac{1}{2}}-101_{2\frac{1}{2}}$						
6193.851	12	16140.59	$a^2G^\circ_{3\frac{1}{2}}-z^4G_{3\frac{1}{2}}$						
6179.852	6	16177.15	$2^\circ_{4\frac{1}{2}}-z^2H_{4\frac{1}{2}}$						
6028.21	5	16584.09	$a^2D^\circ_{2\frac{1}{2}}-z^4G_{3\frac{1}{2}}$						
6018.99	10	16609.49	$4^\circ_{1\frac{1}{2}}-102_{2\frac{1}{2}}$	4	418	(209)	329	1.370	0.952
5961.973	8	16768.34	$a^4F^\circ_{2\frac{1}{2}}-z^4G_{2\frac{1}{2}}$	5	399	(199)	961	1.170	0.771
5914.395	12	16903.23	$a^4G^\circ_{2\frac{1}{2}}-z^4G_{2\frac{1}{2}}$	6	174	(438)	689	0.600	0.775
5893.498	8	16963.16	$3^\circ_{3\frac{1}{2}}-102_{2\frac{1}{2}}$						
5796.439	10	17247.21	$a^2D^\circ_{1\frac{1}{2}}-z^4F_{2\frac{1}{2}}$	5	152	(72)	1225	0.843	0.995
5700.696	8	17536.86	$a^4F^\circ_{3\frac{1}{2}}-z^4G_{3\frac{1}{2}}$						
5657.19	2	17671.73	$a^4G^\circ_{3\frac{1}{2}}-z^4G_{3\frac{1}{2}}$						
5645.888	12	17707.10	$a^2G^\circ_{3\frac{1}{2}}-z^4F_{2\frac{1}{2}}$	7b	—	(0)	978	0.978	0.978
5601.620	6	17847.04	$a^2G^\circ_{3\frac{1}{2}}-101_{2\frac{1}{2}}$						
5539.901	18d	18045.86	$a^4G^\circ_{2\frac{1}{2}}-z^4F_{1\frac{1}{2}}$	4	—	—	581	(0.601)	0.614
5537.127	10	18054.90	$a^4G^\circ_{3\frac{1}{2}}-z^4G_{3\frac{1}{2}}$						
5507.99	2	18150.41	$a^2D^\circ_{2\frac{1}{2}}-z^4F_{3\frac{1}{2}}$						
5478.833	5	18586.24	$4^\circ_{1\frac{1}{2}}-106_{2\frac{1}{2}}$						
5462.615	12	18301.18	$2^\circ_{4\frac{1}{2}}-103_{3\frac{1}{2}}$	—	231	(114)	—	(0.791)	1.022
5449.478	12	18345.30	$2^\circ_{4\frac{1}{2}}-z^2I_{5\frac{1}{2}}$	5	—	—	941	(0.791)	0.818
5433.703	6	18398.56	$a^2G^\circ_{3\frac{1}{2}}-z^4H_{4\frac{1}{2}}$						
5425.679	15d	18425.76	$a^4G^\circ_{2\frac{1}{2}}-y^4F_{1\frac{1}{2}}$	4	109	(52)	432	0.595	0.704
5415.434	20d	18460.62	$2^\circ_{4\frac{1}{2}}-z^4H_{5\frac{1}{2}}$	4	104	(54)	429	0.787	0.891
5304.625	5	18846.24	$3^\circ_{3\frac{1}{2}}-z^4H_{5\frac{1}{2}}$						
5303.046	5	18851.85	$a^4D^\circ_{1\frac{1}{2}}-102_{2\frac{1}{2}}$						
5280.090	6	18933.82	$2^\circ_{4\frac{1}{2}}-105_{3\frac{1}{2}}$						
5277.502	15d	18943.10	$a^2H^\circ_{4\frac{1}{2}}-z^4H_{4\frac{1}{2}}$	6	99	(446)	—	(0.931)	1.030
5233.226	12	19103.37	$a^4F^\circ_{3\frac{1}{2}}-z^4F_{3\frac{1}{2}}$	5	186	(95)	1642	1.174	0.988
5218.528	10	19157.17	$a^4F^\circ_{2\frac{1}{2}}-z^4G_{3\frac{1}{2}}$						
5184.726	3	19282.17	$1^\circ_{3\frac{1}{2}}-102_{2\frac{1}{2}}$						
5170.23	6	19336.13	$a^2G^\circ_{3\frac{1}{2}}-z^2H_{4\frac{1}{2}}$						
5163.446	12	19361.63	$2^\circ_{4\frac{1}{2}}-z^4H_{5\frac{1}{2}}$						
5132.262	5	19479.17	$3^\circ_{3\frac{1}{2}}-109_{4\frac{1}{2}}$						
5095.064	10	19621.38	$a^4G^\circ_{3\frac{1}{2}}-z^4F_{3\frac{1}{2}}$						
5079.141	5	19682.90	$a^2D^\circ_{1\frac{1}{2}}-y^4G_{2\frac{1}{2}}$						
5061.221	12	19752.59	$3^\circ_{3\frac{1}{2}}-111_{2\frac{1}{2}}$						
5049.810	30w	19797.22	$a^4F^\circ_{1\frac{1}{2}}-z^4G_{2\frac{1}{2}}$	5	283	(142)	1204	0.494	0.777
5028.609	40w	19880.69	$a^2H^\circ_{4\frac{1}{2}}-z^2H_{4\frac{1}{2}}$	6	105	(476)	985	0.932	1.037
5017.247	50	19925.71	$a^4F^\circ_{2\frac{1}{2}}-z^4G^\circ_{3\frac{1}{2}}$	4	—	—	986	(1.061)	1.040
4999.938	8	19994.69	$2^\circ_{4\frac{1}{2}}-109_{4\frac{1}{2}}$						
4972.609	3	20104.57	$1^\circ_{3\frac{1}{2}}-103_{3\frac{1}{2}}$						
4963.192	8	20142.72	$a^2G^\circ_{4\frac{1}{2}}-y^4G_{5\frac{1}{2}}$						
4954.569	2	20177.78	$a^2D^\circ_{1\frac{1}{2}}-102_{2\frac{1}{2}}$	5	—	—	—	(0.832)	0.963
4933.541	2	20263.78	$a^4H^\circ_{5\frac{1}{2}}-z^2H_{4\frac{1}{2}}$						
4929.38	2h	20280.88	$4^\circ_{1\frac{1}{2}}-z^4D_{1\frac{1}{2}}$						
4921 610	20	20312.90	$a^4G^\circ_{3\frac{1}{2}}-z^4H_{4\frac{1}{2}}$						
4919.814	50	20320.32	$a^4H^\circ_{5\frac{1}{2}}-z^4G_{5\frac{1}{2}}$	4	—	—	582	(0.718)	0.772
4863.182	20	20556.94	$a^4H^\circ_{4\frac{1}{2}}-z^4G_{5\frac{1}{2}}$						
4856.277	2	20586.17	$a^2D^\circ_{2\frac{1}{2}}-y^4G_{2\frac{1}{2}}$						
4844.124	10	20637.82	$a^2G^\circ_{3\frac{1}{2}}-102_{2\frac{1}{2}}$						
4837.711	2	20665.18	$3^\circ_{3\frac{1}{2}}-y^4H_{4\frac{1}{2}}$						
4822.014	2	20732.45	$a^4F^\circ_{2\frac{1}{2}}-z^2H_{4\frac{1}{2}}$						
4816.862	2	20754.62	$3^\circ_{3\frac{1}{2}}-113_{4\frac{1}{2}}$						
4799.75	1	20828.62	$a^4D^\circ_{1\frac{1}{2}}-106_{2\frac{1}{2}}$						
4774.255	10	20939.84	$a^4F^\circ_{1\frac{1}{2}}-z^4F_{1\frac{1}{2}}$	6	132	(200)	559	0.492	0.624
4742.266	4l	21081.09	$a^2D^\circ_{2\frac{1}{2}}-102_{2\frac{1}{2}}$						
4740.517	20	21088.86	$a^4H^\circ_{5\frac{1}{2}}-z^4G_{5\frac{1}{2}}$	6	314	(1097)	871	0.719	1.033
4729.883	6	21136.28	$a^2F^\circ_{3\frac{1}{2}}-z^4H_{4\frac{1}{2}}$	4	99	—	684	1.125	1.026
4723.452	5	21165.06	$1^\circ_{3\frac{1}{2}}-z^4H_{5\frac{1}{2}}$						
4719.997	4	21180.55	$2^\circ_{4\frac{1}{2}}-y^4H_{5\frac{1}{2}}$	6	262	(1178)	923	0.793	1.055
4719.245	2	21183.92	$4^\circ_{1\frac{1}{2}}-119_{1\frac{1}{2}}$						
4715.436	3	21201.03	$a^2H^\circ_{4\frac{1}{2}}-z^4G_{4\frac{1}{2}}$	6	294	—	1075	0.928	1.222
4712.395	4	21214.71	$a^4G^\circ_{4\frac{1}{2}}-z^2H_{4\frac{1}{2}}$						
4708.076	4w	21234.18	$a^4D^\circ_{3\frac{1}{2}}-104_{4\frac{1}{2}}$	5	621	(310)	1184	0.253	0.874
4700.150	6	21269.99	$2^\circ_{4\frac{1}{2}}-113_{4\frac{1}{2}}$	6	25	(113)	808	0.795	0.820
4689.173	10	21319.78	$a^4F^\circ_{4\frac{1}{2}}-y^4F_{4\frac{1}{2}}$	6	226	(339)	611	0.490	0.716
4685.95	1	21334.44	$3^\circ_{3\frac{1}{2}}-y^4G_{4\frac{1}{2}}$						
4658.50	2	21460.15	$a^2G^\circ_{3\frac{1}{2}}-103_{3\frac{1}{2}}$						
4651.556	30	21492.18	$a^4F^\circ_{2\frac{1}{2}}-z^4F_{2\frac{1}{2}}$	6	72	(179)	1024	1.062	0.990
4639.708	10	21547.07	$1^\circ_{3\frac{1}{2}}-107_{4\frac{1}{2}}$	5	164	(85)	1232	0.986	0.822
4631.762	15	21584.03	$a^4H^\circ_{5\frac{1}{2}}-z^4G_{4\frac{1}{2}}$	4	94	(48)	701	1.119	1.213
4624.142	3	21619.78	$a^2G^\circ_{3\frac{1}{2}}-y^4G_{3\frac{1}{2}}$						
4612.54	4	21673.98	$a^4G^\circ_{3\frac{1}{2}}-y^4G_{2\frac{1}{2}}$						
4606.506	4	21702.37	$1^\circ_{3\frac{1}{2}}-108_{4\frac{1}{2}}$	7b	—	(0)	986	0.986	0.986
4584.376	5	21807.13	$1^\circ_{3\frac{1}{2}}-110_{3\frac{1}{2}}$	5	—	—	1156	(0.982)	1.031
4575.427	4	21849.78	$2^\circ_{4\frac{1}{2}}-y^4G_{4\frac{1}{2}}$	6	238	—	908	0.793	1.031
4564.183	4	21903.61	$a^2D^\circ_{2\frac{1}{2}}-103_{3\frac{1}{2}}$	4	—	—	890	(1.088)	1.031
4544.518	8	21998.38	$a^2F^\circ_{2\frac{1}{2}}-z^4G_{2\frac{1}{2}}$	6	72	(197)	816	0.853	0.781
4543.208	3	22004.73	$a^2H^\circ_{4\frac{1}{2}}-103_{3\frac{1}{2}}$						
4540.425	8	22018.22	$3^\circ_{3\frac{1}{2}}-120_{3\frac{1}{2}}$	6	161	(565)	941	0.862	1.023
4537.070	20	22034.50	$2^\circ_{4\frac{1}{2}}-118_{4\frac{1}{2}}$	5	108	(48)	1366	0.776	0.884
4534.129	10	22048.79	$a^2H^\circ_{4\frac{1}{2}}-z^2I_{5\frac{1}{2}}$	4	101	(50)	373	0.927	0.826
4533.309	12	22052.78	$a^4F^\circ_{3\frac{1}{2}}-z^4G_{4\frac{1}{2}}$	5	—	—	1359	(1.173)	1.215
4529.487	3	22071.39	$1^\circ_{3\frac{1}{2}}-111_{2\frac{1}{2}}$	7b	—	(0)	995	0.995	0.995
4525.10	5	22092.78	$a^2G^\circ_{3\frac{1}{2}}-105_{3\frac{1}{2}}$						
4517.046	4	22132.18	$a^4F^\circ_{4\frac{1}{2}}-z^4F_{3\frac{1}{2}}$						
4512.490	4	22154.52	$a^2D^\circ_{1\frac{1}{2}}-106_{2\frac{1}{2}}$	5	201	(102)	1337	0.833	1.034
4510.535	30	22164.12	$a^2H^\circ_{4\frac{1}{2}}-y^4G_{3\frac{1}{2}}$	5	—	—	992	(0.931)	0.913
4492.239	8	22254.39	$1^\circ_{3\frac{1}{2}}-z^4F_{3\frac{1}{2}}$						
4488.680	25	22272.04	$a^4F^\circ_{4\frac{1}{2}}-101_{3\frac{1}{2}}$	5	370	(184)	1413	0.485	0.855
4485.796	10	22286.36	$a^2D^\circ_{2\frac{1}{2}}-104_{4\frac{1}{2}}$	—	213	(107)	—	(1.088)	0.875
4484.292	5	22293.83	$a^4D^\circ_{3\frac{1}{2}}-107_{4\frac{1}{2}}$						
4456.706	4	22431.82	$a^4H^\circ_{5\frac{1}{2}}-z^2I_{5\frac{1}{2}}$						
4454.517	8	22442.85	$a^2D^\circ_{1\frac{1}{2}}-107_{4\frac{1}{2}}$	7b	—	(0)	825	0.825	0.825
4445.900	4	22486.34	$3^\circ_{3\frac{1}{2}}-123_{3\frac{1}{2}}$						
4439.128	20	22520.65	$a^2G^\circ_{3\frac{1}{2}}-z^4H_{5\frac{1}{2}}$	6	154	(536)	—	0.985	0.831
4436.558	10	22533.69	$2^\circ_{4\frac{1}{2}}-120_{3\frac{1}{2}}$	4	226	(113)	0	0.791	1.017
4436.288	8	22535.06	$a^4G^\circ_{4\frac{1}{2}}-z^4G_{4\frac{1}{2}}$						
4436.046	8	22536.29	$a^2D^\circ_{2\frac{1}{2}}-105_{3\frac{1}{2}}$						
4429.274	5	22570.75	$a^4G^\circ_{3\frac{1}{2}}-z^4G_{4\frac{1}{2}}$						
4416.241	15	22637.36	$a^2H^\circ_{4\frac{1}{2}}-105_{3\frac{1}{2}}$	4	121	(61)	506	0.927	1.048
4412.745	12	22655.29	$a^4H^\circ_{5\frac{1}{2}}-z^4F_{3\frac{1}{2}}$	4	267	(132)	30	0.716	0.983
4391.114	50	22766.89	$a^2F^\circ_{3\frac{1}{2}}-z^4G_{3\frac{1}{2}}$	5	175	(87)	1469	0.856	1.031
4387.101	4	22787.71	$2^\circ_{4\frac{1}{2}}-122_{4\frac{1}{2}}$						
4384.70	12	22800.19	$4^\circ_{1\frac{1}{2}}-126_{3\frac{1}{2}}$						
4381.859	30	22814.98	$a^4H^\circ_{4\frac{1}{2}}-z^4H_{4\frac{1}{2}}$	6	14	(61)	1021	1.014	1.028
4377.271	5	22838.88	$a^4D^\circ_{1\frac{1}{2}}-114_{2\frac{1}{2}}$						
4373.907	10	22856.45	$a^4F^\circ_{3\frac{1}{2}}-103_{3\frac{1}{2}}$	6	148	(516)	1099	1.171	1.023
4369.325	10	22880.42	$a^2F^\circ_{2\frac{1}{2}}-y^4G_{2\frac{1}{2}}$	5	349	(175)	2008	1.130	0.781
4353.404	8	22964.09	$a^2D^\circ_{2\frac{1}{2}}-z^4H_{5\frac{1}{2}}$						
4343.590	4	23015.90	$a^4F^\circ_{3\frac{1}{2}}-y^4G_{3\frac{1}{2}}$						
4335.683	—	23057.96	$a^2G^\circ_{3\frac{1}{2}}-108_{3\frac{1}{2}}$	7b	—	(0)	982	0.982	0.982
4320.597	8	23138.47	$a^4D^\circ_{1\frac{1}{2}}-116_{1\frac{1}{2}}$	7b	—	(0)	1157	(1.167)	1.187
4320.131	12	23140.96	$a^2F^\circ_{3\frac{1}{2}}-z^4F_{4\frac{1}{2}}$	5	232	(115)	1201	0.853	0.621
4318.300	6	23150.77	$a^4G^\circ_{3\frac{1}{2}}-y^4G_{3\frac{1}{2}}$	5	304	(143)	1668	0.603	0.907
4315.957	5	23163.34	$a^4D^\circ_{1\frac{1}{2}}-117_{2\frac{1}{2}}$	4	282	(141)	462	1.166	0.884
4288.056	8	23314.05	$3^\circ_{3\frac{1}{2}}-127_{3\frac{1}{2}}$	4	308	(155)	86	0.859	1.167
4283.525	10	23338.72	$a^4G^\circ_{4\frac{1}{2}}-103_{3\frac{1}{2}}$	—	66	(33)	—	(1.086)	1.020
4282.044	30	23346.79	$a^4H^\circ_{5\frac{1}{2}}-z^4H_{4\frac{1}{2}}$	5	312	(156)	2127	0.720	1.032
4276.974	4	23374.46	$a^4G^\circ_{3\frac{1}{2}}-103_{3\frac{1}{2}}$						
4276.974	4	23374.46	$3^\circ_{3\frac{1}{2}}-128_{3\frac{1}{2}}$						
4276.814	10	23375.34	$a^2F^\circ_{3\frac{1}{2}}-102_{3\frac{1}{2}}$	5	182	—	1578	1.131	0.949
4274.331	8	23388.91	$3^\circ_{3\frac{1}{2}}-129_{4\frac{1}{2}}$						
4273.363	20	23394.21	$a^2F^\circ_{3\frac{1}{2}}-z^4G_{4\frac{1}{2}}$	5	89	(43)	1537	1.140	1.229
4267.519	—	23426.25	$a^4D^\circ_{1\frac{1}{2}}-119_{1\frac{1}{2}}$	6	446	(667)	1389	1.169	1.615
4256.102	12	23489.09	$a^4F^\circ_{3\frac{1}{2}}-105_{3\frac{1}{2}}$	6	122	(429)	1114	1.175	1.053
4254.458	8	23498.16	$a^4G^\circ_{4\frac{1}{2}}-y^4G_{3\frac{1}{2}}$						
4254.02	—	23500.59	$3^\circ_{3\frac{1}{2}}-130_{3\frac{1}{2}}$						
4253.875	6	23501.38	$a^2D^\circ_{2\frac{1}{2}}-108_{2\frac{1}{2}}$						
4250.339	12	23520.94	$a^2F^\circ_{3\frac{1}{2}}-y^4F_{4\frac{1}{2}}$	5	134	(65)	1061	0.858	0.724

TABLE II.—*Continued.*

Wave-length	Arc int.	Wave number	Classification	Type	Sep.	p	n	g_1	g_2
4247.994	15	23533.92	$a^4G^\circ_{3\frac{1}{2}}-y^4G_{3\frac{1}{2}}$	6	—	—	907	0.907	0.907
4238.97	—	23583.87	$4^\circ_{1\frac{1}{2}}-132_{2\frac{1}{2}}$						
4234.989	6	23606.19	$a^2D^\circ_{2\frac{1}{2}}-110_{2\frac{1}{2}}$						
4218.545	8	23698.21	$a^2H^\circ_{4\frac{1}{2}}-109_{4\frac{1}{2}}$	6	—	—	931	0.931	0.931
4218.190	8	23700.20	$a^4D^\circ_{\frac{1}{2}}-z^4D_{\frac{1}{2}}$	7b	—	(0)	259	0.259	0.259
4208.893	15	23752.55	$a^4H^\circ_{4\frac{1}{2}}-z^2H_{4\frac{1}{2}}$	6	9	(81)	1022	1.013	1.031
4191.829	5	23849.24	$a^2D^\circ_{1\frac{1}{2}}-z^4D_{\frac{1}{2}}$	5	564	(285)	1112	0.833	0.269
4184.721	—	23889.75	$2^\circ_{4\frac{1}{2}}-128_{3\frac{1}{2}}$	4	189	—	128	0.788	0.977
4182.159	5	23904.38	$2^\circ_{4\frac{1}{2}}-129_{4\frac{1}{2}}$	6	183	(822)	887	0.797	0.980
4179.965	8	23916.93	$a^4F^\circ_{3\frac{1}{2}}-z^4H_{3\frac{1}{2}}$	6	343	(1201)	1003	1.171	0.828
4178.064	10	23927.81	$a^4F^\circ_{2\frac{1}{2}}-y^4G_{2\frac{1}{2}}$	6	279	(698)	923	1.062	0.783
4176.34	—	23937.69	$3^\circ_{3\frac{1}{2}}-132_{3\frac{1}{2}}$						
4170.475	10l	23971.35	$a^4G^\circ_{4\frac{1}{2}}-105_{3\frac{1}{2}}$						
4168.574	—	23982.28	$a^2H^\circ_{4\frac{1}{2}}-112_{4\frac{1}{2}}$	6	140	(627)	999	0.931	1.071
4164.253	10	24007.17	$a^4G^\circ_{3\frac{1}{2}}-105_{3\frac{1}{2}}$	6	137	(482)	—	(0.911)	1.0 8
4163.653	8	24010.63	$a^4F^\circ_{3\frac{1}{2}}-106_{2\frac{1}{2}}$	5	143	(71)	1527	1.174	1.031
4162.685	10	24016.21	$2^\circ_{4\frac{1}{2}}-130_{3\frac{1}{2}}$	4	154	(76)	246	0.787	0.941
4156.523	10	24051.81	$a^4G^\circ_{2\frac{1}{2}}-z^4H_{3\frac{1}{2}}$	5	228	(115)	1400	0.603	0.831
4156.243	8	24053.43	$a^2D^\circ_{2\frac{1}{2}}-z^4F_{3\frac{1}{2}}$						
4151.45	—	24081.20	$a^4H^\circ_{4\frac{1}{2}}-109_{4\frac{1}{2}}$						
4149.991	10	24089.67	$a^2H^\circ_{4\frac{1}{2}}-z^4H_{4\frac{1}{2}}$	5	65	(35)	1293	0.940	1.005
4140.392	—	24145.52	$a^4G^\circ_{2\frac{1}{2}}-106_{2\frac{1}{2}}$	6	429	(1074)	823	0.607	1.036
4131.433	8	24197.88	$a^2F^\circ_{3\frac{1}{2}}-103_{3\frac{1}{2}}$	6	107	(367)	—	1.133	1.026
4116.718	12	24284.37	$a^4H^\circ_{3\frac{1}{2}}-z^2H_{4\frac{1}{2}}$	5	317	(158)	2147	0.718	1.035
4108.426	15	24333.38	$a^2F^\circ_{3\frac{1}{2}}-z^4F_{3\frac{1}{2}}$	6	130	(326)	921	0.856	0.986
4107.382	—	24339.56	$a^2G^\circ_{3\frac{1}{2}}-y^4H_{4\frac{1}{2}}$						
4104.392	10	24357.30	$a^2F^\circ_{3\frac{1}{2}}-y^4G_{3\frac{1}{2}}$	6	226	(791)	1017	1.130	0.904
4097.339	5	24399.22	$a^4G^\circ_{4\frac{1}{2}}-z^4H_{3\frac{1}{2}}$						
4093.394	10	24422.74	$a^4F^\circ_{3\frac{1}{2}}-102_{2\frac{1}{2}}$	6	111	(277)	1020	1.07	0.96
4091.53	—	24433.87	$a^4G^\circ_{3\frac{1}{2}}-107_{4\frac{1}{2}}$						
4091.344	2h	24434.97	$a^4G^\circ_{3\frac{1}{2}}-z^4H_{3\frac{1}{2}}$						
4085.036	15	24472.70	$a^4H^\circ_{4\frac{1}{2}}-z^4H_{5\frac{1}{2}}$	6	129	(704)	1063	1.127	0.998
4082.263	10	24489.33	$a^2D^\circ_{1\frac{1}{2}}-117_{2\frac{1}{2}}$	5	—	—	953	(0.832)	0.880
4075.713	5	24528.68	$a^4G^\circ_{3\frac{1}{2}}-106_{3\frac{1}{2}}$						
4069.210	40	24567.88	$a^4F^\circ_{1\frac{1}{2}}-y^4G_{2\frac{1}{2}}$	5	286	(144)	1211	0.495	0.781
4068.990	—	24569.21	$a^4F^\circ_{3\frac{1}{2}}-110_{3\frac{1}{2}}$						
4065.687	2h	24589.17	$a^4G^\circ_{3\frac{1}{2}}-108_{3\frac{1}{2}}$	6	384	(961)	796	0.605	0.989
4063.410	10	24602.95	$a^4D^\circ_{\frac{1}{2}}-119_{1\frac{1}{2}}$						
4057.337	10	24639.77	$a^4D^\circ_{1\frac{1}{2}}-125_{1\frac{1}{2}}$	6	164	(246)	—	(1.167)	1.003
4048.448	5	24693.87	$a^4G^\circ_{3\frac{1}{2}}-110_{3\frac{1}{2}}$	5	448	(210)	2146	0.578	1.026
4037.258	8	24762.31	$a^2G^\circ_{3\frac{1}{2}}-115_{3\frac{1}{2}}$	7b	—	(0)	985	0.985	0.985
4030.293	8	24805.11	$1^\circ_{2\frac{1}{2}}-123_{3\frac{1}{2}}$						
4027.330	5	24823.36	$a^4F^\circ_{3\frac{1}{2}}-111_{2\frac{1}{2}}$						
4026.158	10	24830.58	$a^2F^\circ_{3\frac{1}{2}}-105_{3\frac{1}{2}}$	6	79	(273)	1020	(1.132)	1.053
4025.612	20	24833.95	$a^4F^\circ_{3\frac{1}{2}}-112_{4\frac{1}{2}}$	4	102	(49)	713	1.172	1.070
4017.495	8	24884.12	$a^2H^\circ_{4\frac{1}{2}}-y^4H_{4\frac{1}{2}}$						
4007.027	20	24949.13	$a^2G^\circ_{3\frac{1}{2}}-117_{3\frac{1}{2}}$	5	90	(42)	1218	0.991	0.901
4005.549	20w	24958.34	$a^4G^\circ_{3\frac{1}{2}}-111_{2\frac{1}{2}}$						
4003.316	15	24972.26	$a^4G^\circ_{3\frac{1}{2}}-108_{3\frac{1}{2}}$	4	—	—	745	(0.911)	0.977
4003.111	10	24973.54	$a^2H^\circ_{4\frac{1}{2}}-113_{4\frac{1}{2}}$						
3999.95	—	24993.27	$1^\circ_{2\frac{1}{2}}-124_{2\frac{1}{2}}$						
3997.864	10	25006.31	$a^4F^\circ_{3\frac{1}{2}}-z^4F_{3\frac{1}{2}}$	6	226	(785)	1060	1.178	0.952
3997.454	8	25008.88	$a^4G^\circ_{3\frac{1}{2}}-y^4G_{4\frac{1}{2}}$						
3993.725	8	25032.23	$a^4G^\circ_{4\frac{1}{2}}-109_{4\frac{1}{2}}$						
3992.278	10	25041.30	$a^4G^\circ_{4\frac{1}{2}}-110_{3\frac{1}{2}}$						
3992.051	5	25042.72	$a^4D^\circ_{1\frac{1}{2}}-126_{2\frac{1}{2}}$						
3988.852	10	25062.81	$a^4F^\circ_{1\frac{1}{2}}-102_{2\frac{1}{2}}$						
3988.015	50	25068.07	$a^4G^\circ_{3\frac{1}{2}}-109_{4\frac{1}{2}}$						
3988.015	50	25068.07	$a^2D^\circ_{2\frac{1}{2}}-114_{2\frac{1}{2}}$						
3982.236	3	25104.45	$3^\circ_{3\frac{1}{2}}-143_{4\frac{1}{2}}$						
3976.418	15	25141.18	$a^4G^\circ_{3\frac{1}{2}}-z^4F_{3\frac{1}{2}}$	5	348	(175)	1823	0.605	0.953
3969.834	5	25182.87	$2^\circ_{4\frac{1}{2}}-140_{3\frac{1}{2}}$						
3966.72	3	25202.64	$a^4D^\circ_{1\frac{1}{2}}-127_{2\frac{1}{2}}$						
3956.603	10	25267.08	$a^4H^\circ_{4\frac{1}{2}}-y^4H_{4\frac{1}{2}}$	5	—	—	1414	(1.128)	1.065
3950.394	30	25306.79	$a^2H^\circ_{4\frac{1}{2}}-115_{3\frac{1}{2}}$	4	—	—	769	(0.931)	0.977
3948.908	—	25316.32	$a^4G^\circ_{4\frac{1}{2}}-112_{4\frac{1}{2}}$	6	16	(74)	1079	1.087	1.071
3943.345	2h	25352.03	$a^4G^\circ_{3\frac{1}{2}}-112_{4\frac{1}{2}}$	5	155	(81)	1603	0.906	1.061
3943.345	2h	25352.03	$a^2F^\circ_{3\frac{1}{2}}-106_{2\frac{1}{2}}$						
3942.646	10	25356.53	$a^4H^\circ_{4\frac{1}{2}}-113_{4\frac{1}{2}}$						
3937.043	15	25392.61	$a^2D^\circ_{2\frac{1}{2}}-117_{3\frac{1}{2}}$	6	203	(506)	988	1.089	0.886
3935.180	5	25404.63	$a^4F^\circ_{2\frac{1}{2}}-y^4G_{3\frac{1}{2}}$						
3932.230	15	25423.69	$a^4G^\circ_{4\frac{1}{2}}-z^4H_{5\frac{1}{2}}$						
3922.221	8	25488.57	$a^4G^\circ_{4\frac{1}{2}}-z^4F_{3\frac{1}{2}}$						
3916.730	15	25524.30	$a^4G^\circ_{3\frac{1}{2}}-z^4F_{3\frac{1}{2}}$						
3912.285	15	25553.30	$a^2H^\circ_{4\frac{1}{2}}-y^4G_{4\frac{1}{2}}$	6	105	(471)	987	0.932	1.037
3902.122	10	25619.85	$2^\circ_{4\frac{1}{2}}-143_{4\frac{1}{2}}$						
3900.886	30	25627.98	$a^4F^\circ_{3\frac{1}{2}}-104_{4\frac{1}{2}}$	5	187	(94)	1344	1.064	0.877
3900.139	2	25632.88	$1^\circ_{2\frac{1}{2}}-127_{3\frac{1}{2}}$						
3891.060	10	25692.68	$a^2G^\circ_{3\frac{1}{2}}-120_{3\frac{1}{2}}$						
3884.531	10	25735.87	$a^4F^\circ_{3\frac{1}{2}}-y^4H_{4\frac{1}{2}}$	4	118	(62)	—	1.170	1.052
3866.894	2	25853.25	$3^\circ_{3\frac{1}{2}}-148_{3\frac{1}{2}}$	7b	—	(0)	864	0.864	0.864
3863.391	20	25876.69	$a^4H^\circ_{4\frac{1}{2}}-103_{3\frac{1}{2}}$	7b	—	(0)	992	(1.018)	1.026
3861.547	—	25889.05	$a^2D^\circ_{1\frac{1}{2}}-124_{2\frac{1}{2}}$	5	218	(108)	1382	0.840	1.058
3859.832	5	25900.55	$a^2F^\circ_{2\frac{1}{2}}-110_{3\frac{1}{2}}$	6	87	(304)	1087	1.044	1.131
3854.507	—	25936.33	$a^4H^\circ_{4\frac{1}{2}}-y^4G_{4\frac{1}{2}}$	5	89	(43)	1533	1.134	1.045
3852.962	8	25946.73	$a^2G^\circ_{3\frac{1}{2}}-122_{4\frac{1}{2}}$	7b	—	—	1051	(0.983)	0.999
3850.136	—	25965.77	$a^2D^\circ_{1\frac{1}{2}}-125_{1\frac{1}{2}}$	6	172	(261)	919	0.829	1.001
3841.964	20	26021.01	$a^4F^\circ_{3\frac{1}{2}}-114_{2\frac{1}{2}}$	5	221	(110)	1728	1.174	0.953
3839.749	—	26036.01	$a^4H^\circ_{4\frac{1}{2}}-y^4G_{3\frac{1}{2}}$	5	106	(54)	1397	1.024	0.918
3825.040	8	26136.13	$a^2D^\circ_{2\frac{1}{2}}-120_{3\frac{1}{2}}$	4	—	—	0.898	(1.088)	1.033
3822.149	10	26155.90	$a^4G^\circ_{3\frac{1}{2}}-114_{2\frac{1}{2}}$	6	355	—	769	0.595	0.950
3821.431	15	26160.81	$a^2G^\circ_{3\frac{1}{2}}-123_{3\frac{1}{2}}$	6	102	(352)	930	0.982	0.880
3819.28	2	26175.54	$a^2F^\circ_{3\frac{1}{2}}-112_{4\frac{1}{2}}$						
3813.064	15	26218.21	$a^4G^\circ_{4\frac{1}{2}}-y^4H_{4\frac{1}{2}}$	6	28	(124)	1073	1.087	1.059
3807.875	10	26253.94	$a^4G^\circ_{3\frac{1}{2}}-y^4H_{4\frac{1}{2}}$	5	143	(71)	1566	0.921	1.064
3805.824	20	26268.09	$a^4F^\circ_{1\frac{1}{2}}-104_{1\frac{1}{2}}$	6	380	(570)	681	0.490	0.870
3802.150	8	26293.47	$a^4G^\circ_{3\frac{1}{2}}-115_{3\frac{1}{2}}$						
3800.378	5	26305.73	$a^4F^\circ_{2\frac{1}{2}}-z^4H_{3\frac{1}{2}}$	4	228	(116)	253	1.053	0.825
3794.341	10	26347.59	$a^2F^\circ_{3\frac{1}{2}}-z^4F_{3\frac{1}{2}}$						
3794.154	10	26348.88	$a^2G^\circ_{3\frac{1}{2}}-124_{2\frac{1}{2}}$	4	—	—	850	(0.983)	1.035
3791.302	8	26368.70	$a^2D^\circ_{1\frac{1}{2}}-126_{2\frac{1}{2}}$	5	—	—	978	(0.832)	0.890
3786.884	15	26399.47	$a^4F^\circ_{3\frac{1}{2}}-106_{2\frac{1}{2}}$	6	22	(55)	—	(1.061)	1.039
3785.603	15	26408.40	$a^4H^\circ_{3\frac{1}{2}}-103_{3\frac{1}{2}}$	6	306	1072	870	0.729	1.035
3775.319	20	26480.33	$a^4G^\circ_{2\frac{1}{2}}-117_{3\frac{1}{2}}$						
3773.760	20	26491.27	$a^2H^\circ_{4\frac{1}{2}}-122_{4\frac{1}{2}}$	6	68	(305)	980	(0.931)	0.999
3768.437	8	26528.69	$a^2D^\circ_{1\frac{1}{2}}-127_{2\frac{1}{2}}$	5	345	(171)	1693	0.833	1.178
3767.23	10	26537.19	$3^\circ_{3\frac{1}{2}}-150_{2\frac{1}{2}}$	—	238	(111)	—	(0.862)	1.100
3762.885	20	26567.83	$a^4H^\circ_{3\frac{1}{2}}-y^4G_{3\frac{1}{2}}$	6	185	(649)	810	0.719	0.904
3752.573	40	26640.84	$a^4G^\circ_{4\frac{1}{2}}-115_{3\frac{1}{2}}$	5	103	(54)	1440	1.094	0.991
3747.547	30	26676.57	$a^4G^\circ_{3\frac{1}{2}}-115_{3\frac{1}{2}}$	6	69	(242)	980	(0.911)	0.980
3745.983	15	26687.70	$a^4F^\circ_{3\frac{1}{2}}-107_{4\frac{1}{2}}$	5	236	(117)	1419	1.064	0.828
3743.513	8	26705.31	$a^2H^\circ_{4\frac{1}{2}}-123_{3\frac{1}{2}}$						
3734.601	8	26769.04	$a^2F^\circ_{3\frac{1}{2}}-y^4G_{3\frac{1}{2}}$	6	72	(180)	840	(0.857)	0.785
3719.969	2	26874.33	$a^4H^\circ_{4\frac{1}{2}}-122_{4\frac{1}{2}}$						
3718.167	15	26887.35	$a^4G^\circ_{4\frac{1}{2}}-y^4G_{4\frac{1}{2}}$						
3711.309	30	26937.04	$a^4H^\circ_{4\frac{1}{2}}-z^4H_{3\frac{1}{2}}$	5	184	(90)	1657	1.016	0.832
3698.305	12	27031.75	$a^4D^\circ_{1\frac{1}{2}}-133_{1\frac{1}{2}}$	5	682	(343)	1274	0.253	0.935
3697.034	6	27041.04	$a^4H^\circ_{3\frac{1}{2}}-105_{3\frac{1}{2}}$						
3695.980	8	27048.75	$a^2G^\circ_{3\frac{1}{2}}-128_{3\frac{1}{2}}$	7b	—	(0)	984	0.984	0.984
3692.080	8	27077.32	$a^2F^\circ_{3\frac{1}{2}}-y^4H_{4\frac{1}{2}}$						
3690.490	10	27088.99	$a^4F^\circ_{3\frac{1}{2}}-120_{3\frac{1}{2}}$	6	150	(523)	1102	1.175	1.025
3683.332	5	27141.63	$a^4D^\circ_{\frac{1}{2}}-136_{1\frac{1}{2}}$	6	692	(346)	—	(0.255)	0.947
3681.886	8	27152.29	$a^2D^\circ_{1\frac{1}{2}}-132_{2\frac{1}{2}}$	5	425	(212)	1892	0.833	1.258
3678.791	3	27175.13	$a^2G^\circ_{3\frac{1}{2}}-130_{3\frac{1}{2}}$						
3673.799	10	27212.06	$a^4F^\circ_{3\frac{1}{2}}-111_{2\frac{1}{2}}$	6	56	(140)	1029	1.057	1.001
3665.731	6	27271.95	$a^2D^\circ_{2\frac{1}{2}}-126_{3\frac{1}{2}}$	6	195	(486)	997	1.095	0.900
3663.204	4	27290.76	$a^2D^\circ_{1\frac{1}{2}}-136_{2\frac{1}{2}}$						
3658.235	—	27327.83	$a^4F^\circ_{1\frac{1}{2}}-107_{1\frac{1}{2}}$	6	333	(500)	—	(0.492)	0.825
3656.204	10	27343.01	$a^4F^\circ_{3\frac{1}{2}}-122_{4\frac{1}{2}}$	4	174	(88)	394	1.179	1.005
3653.59	3	27362.57	$a^2F^\circ_{3\frac{1}{2}}-114_{2\frac{1}{2}}$	—	179	—	—	(1.132)	0.953
3649.251	10	27395.11	$a^4F^\circ_{3\frac{1}{2}}-z^4F_{3\frac{1}{2}}$	4	107	(55)	680	1.052	0.945
3646.886	5	27412.87	$2^\circ_{4\frac{1}{2}}-153_{3\frac{1}{2}}$						
3645.250	2	27425.18	$a^4D^\circ_{\frac{1}{2}}-138_{1\frac{1}{2}}$						
3644.347	5	27431.97	$a^2D^\circ_{2\frac{1}{2}}-127_{3\frac{1}{2}}$	6	82	(205)	—	(1.088)	1.170
3639.449	10	27468.88	$a^4H^\circ_{3\frac{1}{2}}-z^4H_{3\frac{1}{2}}$	6	109	(338)	775	0.721	0.830
3637.557	8	27483.17	$a^4F^\circ_{1\frac{1}{2}}-108_{2\frac{1}{2}}$	5	495	(246)	1734	0.497	0.992

TABLE II.—*Continued.*

Wave-length	Arc int.	Wave number	Classification	Type	Sep.	p	n	g_1	g_2
3625.940	6	27571.22	$a^4G^\circ_{4\frac{1}{2}}-120_{4\frac{1}{2}}$	5	—	—	1295	(1.086)	1.028
3624.898	8	27579.15	$a^4H^\circ_{4\frac{1}{2}}-110_{3\frac{1}{2}}$	4	—	—	957	(1.018)	1.036
3623.035	3	27593.33	$a^2H^\circ_{4\frac{1}{2}}-128_{3\frac{1}{2}}$						
3621.121	10	27607.91	$a^2H^\circ_{4\frac{1}{2}}-129_{4\frac{1}{2}}$	6	43	(194)	955	0.933	0.976
3619.711	4	27618.67	$a^2D^\circ_{2\frac{1}{2}}-130_{3\frac{1}{2}}$	4	136	(67)	601	1.080	0.944
3603.624	4	27741.96	$a^4D^\circ_{1\frac{1}{2}}-148_{2\frac{1}{2}}$						
3603.208	8	27745.16	$a^4F^\circ_{3\frac{1}{2}}-124_{3\frac{1}{2}}$	5	125	(62)	1478	1.165	1.040
3602.464	4	27750.89	$1^\circ_{2\frac{1}{2}}-145_{1\frac{1}{2}}$						
3595.323	3*d*	27806.01	$1^\circ_{2\frac{1}{2}}-146_{1\frac{1}{2}}$	5	279	(141)	1412	0.997	0.718
3593.881	5	27817.16	$a^2H^\circ_{4\frac{1}{2}}-131_{3\frac{1}{2}}$	4	163	—	370	0.930	1.093
3589.362	—	27852.19	$a^4F^\circ_{4\frac{1}{2}}-111_{3\frac{1}{2}}$	5	509	(251)	1766	0.494	1.003
3589.109	4	27854.15	$a^4H^\circ_{4\frac{1}{2}}-112_{4\frac{1}{2}}$						
3585.774	4	27880.05	$a^4G^\circ_{3\frac{1}{2}}-124_{3\frac{1}{2}}$	6	447	(1123)	826	0.601	1.048
3576.562	3	27951.86	$4^\circ_{1\frac{1}{2}}-156_{2\frac{1}{2}}$						
3575.323	6	27961.55	$a^4H^\circ_{4\frac{1}{2}}-z^4H_{5\frac{1}{2}}$	7b	—	—	951	(1.018)	1.006
3571.575	8	27990.89	$a^4H^\circ_{4\frac{1}{2}}-129_{4\frac{1}{2}}$	5	148	(78)	1795	1.133	0.985
3569.627	2	28006.16	$a^4H^\circ_{5\frac{1}{2}}-108_{3\frac{1}{2}}$						
3567.707	3	28021.23	$a^4D^\circ_{1\frac{1}{2}}-149_{2\frac{1}{2}}$						
3567.046	4	28026.43	$a^4H^\circ_{4\frac{1}{2}}-z^4F_{4\frac{1}{2}}$						
3560.864	10	28075.08	$a^4G^\circ_{5\frac{1}{2}}-123_{4\frac{1}{2}}$						
3557.464	5	28101.91	$a^4H^\circ_{3\frac{1}{2}}-109_{4\frac{1}{2}}$	5	219	(105)	1707	0.721	0.940
3556.312	2*d*	28110.96	$a^4H^\circ_{3\frac{1}{2}}-110_{3\frac{1}{2}}$						
3549.741	4	28163.05	$a^2D^\circ_{2\frac{1}{2}}-134_{1\frac{1}{2}}$	5	—	—	1180	(1.088)	1.028
3546.260	5	28190.70	$a^2D^\circ_{2\frac{1}{2}}-135_{2\frac{1}{2}}$						
3541.977	2	28224.79	$a^4F^\circ_{3\frac{1}{2}}-126_{2\frac{1}{2}}$						
3539.325	5	28245.93	$a^2F^\circ_{2\frac{1}{2}}-y^4G_{3\frac{1}{2}}$	5	—	—	996	(0.857)	0.897
3537.161	10	28263.21	$a^4G^\circ_{4\frac{1}{2}}-124_{3\frac{1}{2}}$	4	134	(66)	577	0.909	1.043
3527.350	4*d*	28341.82	$a^2G^\circ_{4\frac{1}{2}}-140_{3\frac{1}{2}}$						
3525.142	2*d*	28359.57	$a^4G^\circ_{5\frac{1}{2}}-126_{2\frac{1}{2}}$						
3518.894	3*d*	28409.93	$a^4F^\circ_{2\frac{1}{2}}-114_{2\frac{1}{2}}$						
3516.357	5	28430.42	$a^2F^\circ_{3\frac{1}{2}}-120_{3\frac{1}{2}}$						
3515.712	5	28435.64	$a^2G^\circ_{4\frac{1}{2}}-141_{4\frac{1}{2}}$						
3513.758	3	28451.45	$1^\circ_{2\frac{1}{2}}-149_{2\frac{1}{2}}$						
3512.746	5	28459.65	$a^4F^\circ_{4\frac{1}{2}}-129_{4\frac{1}{2}}$	4	195	(97)	291	1.168	0.973
3511.553	—	28469.32	$a^2F^\circ_{3\frac{1}{2}}-104_{1\frac{1}{2}}$	7b	—	—	831	(0.857)	0.874
3510.540	5	28477.53	$a^2D^\circ_{2\frac{1}{2}}-138_{3\frac{1}{2}}$						
3501.94	3	28547.46	$a^4F^\circ_{2\frac{1}{2}}-115_{2\frac{1}{2}}$						
3498.986	8	28571.56	$a^4F^\circ_{3\frac{1}{2}}-130_{3\frac{1}{2}}$	6	226	(788)	—	(1.173)	0.947
3489.832	4	28646.51	$a^2D^\circ_{1\frac{1}{2}}-145_{1\frac{1}{2}}$						
3487.849	10	28662.79	$4^\circ_{1\frac{1}{2}}-159_{1\frac{1}{2}}$	6	155	(228)	1291	1.367	1.212
3487.08	4	28669.11	$a^4F^\circ_{4\frac{1}{2}}-131_{3\frac{1}{2}}$						
3485.216	8	28684.45	$a^2F^\circ_{3\frac{1}{2}}-122_{4\frac{1}{2}}$	4	131	(64)	549	1.130	0.999
3484.086	8	28693.74	$a^2D^\circ_{2\frac{1}{2}}-139_{2\frac{1}{2}}$	6	42	(106)	1110	1.089	1.131
3482.552	10	28706.39	$a^4G^\circ_{5\frac{1}{2}}-130_{4\frac{1}{2}}$	5	349	(177)	1820	0.599	0.948
3481.051	5	28719.16	$a^2F^\circ_{3\frac{1}{2}}-105_{3\frac{1}{2}}$						
3479.177	15	28734.23	$a^4F^\circ_{4\frac{1}{2}}-z^4D_{5\frac{1}{2}}$	5	229	(114)	611	0.496	0.267
3478.136	10	28742.83	$a^4G^\circ_{5\frac{1}{2}}-126_{2\frac{1}{2}}$	7b	—	—	942	(0.911)	0.899
3476.543	10	28756.00	$a^4H^\circ_{4\frac{1}{2}}-y^4H_{4\frac{1}{2}}$	6	39	(174)	—	(1.018)	1.057
3474.304	6	28774.53	$a^4D^\circ_{1\frac{1}{2}}-152_{1\frac{1}{2}}$						
3473.784	5	28778.83	$a^2G^\circ_{5\frac{1}{2}}-143_{4\frac{1}{2}}$						
3465.766	10	28845.42	$a^4H^\circ_{4\frac{1}{2}}-113_{4\frac{1}{2}}$	6	190	(855)	911	1.011	0.821
3455.949	4	28927.35	$a^4G^\circ_{4\frac{1}{2}}-128_{3\frac{1}{2}}$						
3454.208	8	28941.93	$a^4G^\circ_{4\frac{1}{2}}-129_{4\frac{1}{2}}$						
3451.703	8	28962.94	$a^4G^\circ_{5\frac{1}{2}}-128_{3\frac{1}{2}}$						
3449.951	5	28977.65	$a^4G^\circ_{5\frac{1}{2}}-129_{4\frac{1}{2}}$						
3449.648	8	28980.19	$a^2H^\circ_{4\frac{1}{2}}-141_{4\frac{1}{2}}$	6	160	(723)	1007	0.930	1.098
3447.631	3	28997.15	$a^4F^\circ_{2\frac{1}{2}}-119_{1\frac{1}{2}}$	4	556	(273)	230	1.065	1.621
3445.748	8	29012.99	$3^\circ_{3\frac{1}{2}}-158_{3\frac{1}{2}}$	6	163	(567)	938	0.860	1.023
3445.382	10	29016.07	$1^\circ_{2\frac{1}{2}}-151_{2\frac{1}{2}}$	7b	—	—	1039	(0.982)	0.998
3444.047	5	29027.32	$a^2D^\circ_{2\frac{1}{2}}-142_{2\frac{1}{2}}$	7b	—	—	1092	1.092	1.092
3441.366	8	29049.93	$a^4F^\circ_{4\frac{1}{2}}-114_{2\frac{1}{2}}$	5	468	(237)	1639	0.470	0.938
3437.027	5	29086.60	$a^2F^\circ_{3\frac{1}{2}}-124_{2\frac{1}{2}}$						
3436.687	3*d*	29089.48	$a^4G^\circ_{5\frac{1}{2}}-130_{3\frac{1}{2}}$	6	31	(110)	—	(0.911)	0.942
3430.342	2*d*	29143.29	$a^4G^\circ_{5\frac{1}{2}}-132_{3\frac{1}{2}}$						
3429.904	6	29147.01	$a^2F^\circ_{3\frac{1}{2}}-z^4H_{3\frac{1}{2}}$	7b	—	—	793	(0.857)	0.839
3429.392	6	29151.36	$a^4G^\circ_{4\frac{1}{2}}-131_{3\frac{1}{2}}$	7b	—	—	1090	1.090	1.090
3426.939	3	29172.23	$a^4G^\circ_{2\frac{1}{2}}-133_{1\frac{1}{2}}$						
3425.190	5	29187.12	$a^4G^\circ_{5\frac{1}{2}}-131_{3\frac{1}{2}}$	6	175	(612)	996	0.908	1.083
3423.131	5	29204.68	$1^\circ_{2\frac{1}{2}}-152_{1\frac{1}{2}}$	4	233	(116)	633	0.982	1.215
3418.931	2*d*	29240.55	$a^2F^\circ_{3\frac{1}{2}}-106_{2\frac{1}{2}}$						
3417.730	3	29250.83	$a^4G^\circ_{3\frac{1}{2}}-131_{1\frac{1}{2}}$						
3414.513	6	29278.38	$a^4G^\circ_{5\frac{1}{2}}-135_{2\frac{1}{2}}$	6	364	(908)	782	0.600	0.964
3413.409	5	29287.85	$a^4H^\circ_{5\frac{1}{2}}-y^4H_{4\frac{1}{2}}$						
3409.273	6	29323.38	$a^2H^\circ_{4\frac{1}{2}}-143_{4\frac{1}{2}}$	6	92	(416)	988	0.934	1.026
3406.243	4	29349.47	$a^4F^\circ_{4\frac{1}{2}}-116_{3\frac{1}{2}}$	4	718	(359)	131	0.490	1.208
3404.654	4	29363.16	$a^4H^\circ_{4\frac{1}{2}}-141_{4\frac{1}{2}}$	7b	—	—	1245	(1.128)	1.102
3390.781	2	29483.30	$a^4G^\circ_{5\frac{1}{2}}-137_{3\frac{1}{2}}$						
3385.537	6	29528.96	$a^2F^\circ_{3\frac{1}{2}}-107_{1\frac{1}{2}}$	7b	—	—	881	(0.857)	0.841
3381.375	5	29565.31	$a^4G^\circ_{2\frac{1}{2}}-138_{1\frac{1}{2}}$						
3380.495	2	29573.01	$a^4H^\circ_{3\frac{1}{2}}-114_{2\frac{1}{2}}$						
3376.818	2	29601.94	$a^2D^\circ_{2\frac{1}{2}}-146_{1\frac{1}{2}}$	5	381	(190)	1664	1.091	0.710
3370.405	2*d*	29661.53	$a^4G^\circ_{5\frac{1}{2}}-135_{2\frac{1}{2}}$						
3367.823	8	29684.27	$a^2F^\circ_{3\frac{1}{2}}-108_{2\frac{1}{2}}$	6	131	(328)	932	0.862	0.993
3364.594	—	29712.76	$3^\circ_{3\frac{1}{2}}-162_{3\frac{1}{2}}$	6	196	(685)	—	(0.862)	1.058
3363.089	—	29726.26	$a^2F^\circ_{3\frac{1}{2}}-127_{2\frac{1}{2}}$	7b	—	—	1062	(1.132)	1.160
3361.739	4*d*	29738.00	$a^4F^\circ_{3\frac{1}{2}}-140_{3\frac{1}{2}}$	6	192	(671)	—	1.158	0.966
3360.161	2	29751.96	$a^2D^\circ_{1\frac{1}{2}}-150_{2\frac{1}{2}}$	5	272	(140)	1510	0.835	1.107
3359.070	1	29761.62	$3^\circ_{3\frac{1}{2}}-163_{2\frac{1}{2}}$						
3354.618	5	29801.12	$a^2F^\circ_{3\frac{1}{2}}-129_{4\frac{1}{2}}$						
3353.96	5	29806.97	$a^2G^\circ_{4\frac{1}{2}}-149_{3\frac{1}{2}}$	7b	—	—	977	0.977	0.977
3350.311	2	29839.43	$a^2H^\circ_{4\frac{1}{2}}-147_{3\frac{1}{2}}$						
3346.559	4	29872.88	$a^4G^\circ_{5\frac{1}{2}}-140_{3\frac{1}{2}}$	5	377	(185)	1929	0.608	0.985
3343.815	3	29897.40	$a^4H^\circ_{5\frac{1}{2}}-117_{2\frac{1}{2}}$						
3338.400	8	29945.89	$a^4F^\circ_{2\frac{1}{2}}-123_{3\frac{1}{2}}$	4	179	(92)	—	(1.061)	0.882
3337.16	6	29957.02	$a^4H^\circ_{3\frac{1}{2}}-y^4G_{4\frac{1}{2}}$						
3331.20	3	30010.61	$a^2F^\circ_{3\frac{1}{2}}-131_{2\frac{1}{2}}$						
3327.194	5	30046.74	$1^\circ_{2\frac{1}{2}}-154_{3\frac{1}{2}}$	5	—	(0)	1300	(0.982)	1.072
3326.468	15	30053.30	$a^2F^\circ_{3\frac{1}{2}}-111_{3\frac{1}{2}}$	6	143	(358)	930	0.860	1.000
3320.302	10	30109.11	$a^4H^\circ_{4\frac{1}{2}}-120_{3\frac{1}{2}}$	7b	—	—	1001	(1.018)	1.023
3319.63	3	30115.20	$a^4G^\circ_{2\frac{1}{2}}-142_{2\frac{1}{2}}$						
3318.981	8	30121.09	$a^4F^\circ_{1\frac{1}{2}}-121_{1\frac{1}{2}}$	4	246	(123)	361	0.489	0.735
3317.571	6*d*	30133.89	$a^4F^\circ_{2\frac{1}{2}}-124_{2\frac{1}{2}}$	7b	—	—	1053	1.053	1.053
3309.137	6	30210.69	$a^4F^\circ_{2\frac{1}{2}}-125_{1\frac{1}{2}}$	5	—	—	1123	(1.061)	1.018
3308.071	2	30220.43	$a^4G^\circ_{4\frac{1}{2}}-140_{3\frac{1}{2}}$						
3304.174	—	30256.07	$a^4G^\circ_{5\frac{1}{2}}-140_{3\frac{1}{2}}$	6	57	(200)	900	(0.911)	0.968
3297.828	10	30314.29	$a^4G^\circ_{4\frac{1}{2}}-141_{4\frac{1}{2}}$	7b?	—	—	1091	1.091	1.091
3296.607	8	30325.52	$a^4D^\circ_{1\frac{1}{2}}-157_{2\frac{1}{2}}$	5	—	—	1152	1.15	1.15
3293.943	10	30350.04	$a^4G^\circ_{5\frac{1}{2}}-141_{4\frac{1}{2}}$	5	176	(86)	1740	0.925	1.101
3292.518	10	30363.18	$a^4H^\circ_{4\frac{1}{2}}-122_{4\frac{1}{2}}$	6	—	—	1008	1.008	1.008
3281.415	8	30465.91	$4^\circ_{1\frac{1}{2}}-166_{2\frac{1}{2}}$						
3269.469	10	30577.22	$a^4H^\circ_{4\frac{1}{2}}-123_{3\frac{1}{2}}$	5	135	(68)	1488	1.022	0.887
3265.60	8	30613.45	$a^4F^\circ_{2\frac{1}{2}}-126_{2\frac{1}{2}}$	6	164	(411)	978	1.065	0.901
3264.437	6	30624.36	$1^\circ_{2\frac{1}{2}}-156_{2\frac{1}{2}}$	7b	—	(0)	986	0.986	0.986
3263.033	8	30637.53	$a^4G^\circ_{2\frac{1}{2}}-145_{1\frac{1}{2}}$						
3262.671	12	30640.93	$a^4H^\circ_{3\frac{1}{2}}-120_{3\frac{1}{2}}$	6	306	(1068)	867	0.715	1.021
3260.922	8	30657.36	$a^4G^\circ_{4\frac{1}{2}}-143_{4\frac{1}{2}}$						
3257.162	8	30692.75	$a^4G^\circ_{2\frac{1}{2}}-146_{1\frac{1}{2}}$	4	—	500	500	(0.601)	0.67
3248.554	4*d*	30774.08	$a^4F^\circ_{1\frac{1}{2}}-124_{2\frac{1}{2}}$						
3243.77	3	30819.46	$3^\circ_{3\frac{1}{2}}-166_{2\frac{1}{2}}$						
3242.257	8	30833.85	$a^4F^\circ_{2\frac{1}{2}}-128_{3\frac{1}{2}}$						
3240.476	10	30850.79	$a^4F^\circ_{4\frac{1}{2}}-125_{4\frac{1}{2}}$						
3235.843	12	30894.96	$a^4H^\circ_{3\frac{1}{2}}-122_{4\frac{1}{2}}$	5	280	(141)	1985	0.725	1.005
3233.62	8	30916.20	$a^2H^\circ_{4\frac{1}{2}}-151_{2\frac{1}{2}}$						
3229.014	12	30960.30	$a^4F^\circ_{2\frac{1}{2}}-130_{3\frac{1}{2}}$	4	112	(52)	675	1.067	0.955
3226.121	10	30987.97	$a^2F^\circ_{3\frac{1}{2}}-139_{2\frac{1}{2}}$	7b?	—	—	1111	(1.132)	1.140
3223.284	5	31015.33	$a^2D^\circ_{2\frac{1}{2}}-153_{3\frac{1}{2}}$	4	150	(76)	122	(1.088)	0.938
3218.864	—	31057.92	$a^4F^\circ_{2\frac{1}{2}}-131_{3\frac{1}{2}}$	5	—	—	1130	(1.061)	1.082
3213.573	12	31109.06	$a^4H^\circ_{3\frac{1}{2}}-123_{3\frac{1}{2}}$	6	160	(557)	795	0.714	0.874
3212.811	6	31116.43	$a^2H^\circ_{4\frac{1}{2}}-153_{3\frac{1}{2}}$	7b?	—	—	907	(0.931)	0.938
3206.935	10	31173.45	$a^4G^\circ_{4\frac{1}{2}}-147_{3\frac{1}{2}}$	7b	—	(0)	1052	(1.086)	1.097
3206.935	10	31173.45	$a^2F^\circ_{3\frac{1}{2}}-141_{4\frac{1}{2}}$	7b	—	(0)	1052	(1.132)	1.114
3203.868	10	31203.28	$a^4F^\circ_{3\frac{1}{2}}-149_{2\frac{1}{2}}$						
3203.255	10	31209.25	$a^4G^\circ_{3\frac{1}{2}}-147_{3\frac{1}{2}}$						
3200.557	—	31235.56	$a^2G^\circ_{4\frac{1}{2}}-a153_{3\frac{1}{2}}$	4	142	(73)	608	0 969	1.111
3198.702	9	31253.68	$a^4F^\circ_{1\frac{1}{2}}-126_{2\frac{1}{2}}$						
3190.73	3	31331.76	$1^\circ_{2\frac{1}{2}}-158_{3\frac{1}{2}}$						

TABLE II.—*Continued.*

Wave-length	Arc int.	Wave number	Classification	Type	Sep.	p	n	g_1	g_2
3190.34	5	31335.59	$1°_2 - 150_{1\frac{1}{2}}$						
3190.074	5	31338.20	$a^4G°_2 - 149_{2\frac{1}{2}}$	6	400	(1000)	—	(0.601)	1.001
3184.952	10	31388.60	$a^2F°_2 - 115_{3\frac{1}{2}}$	5	127	(62)	1311	0.869	0.996
3183.554	8	31402.39	$a^2G°_2 - 154_{3\frac{1}{2}}$						
3182.403	10	31413.74	$a^4F°_{1\frac{1}{2}} - 127_{2\frac{1}{2}}$						
3181.189	10	31425.73	$a^4F°_{3\frac{1}{2}} - 133_{1\frac{1}{2}}$	5	124	(63)	1257	1.071	0.947
3177.874	5	31458.51	$4°_{1\frac{1}{2}} - 168_{2\frac{1}{2}}$	4	248	(123)	720	1.35	1.10
3177.198	10	31465.20	$a^4H°_{4\frac{1}{2}} - 128_{3\frac{1}{2}}$	7b	—	—	1084	(1.018)	0.999
3175.730	12	31479.75	$a^4H°_{4\frac{1}{2}} - 129_{4\frac{1}{2}}$	6	31	(138)	1001	1.016	0.985
3173.214	8	31504.71	$a^4F°_{2\frac{1}{2}} - 134_{1\frac{1}{2}}$	7b	—	—	1113	(1.061)	0.966
3171.665	5*d*	31520.09	$a^2D°_{1\frac{1}{2}} - 156_{2\frac{1}{2}}$						
3170.429	10	31532.38	$a^4F°_{3\frac{1}{2}} - 135_{3\frac{1}{2}}$	6	95	(238)	—	(1.061)	0.966
3166.102	—	31575.47	$a^2F°_{2\frac{1}{2}} - 117_{2\frac{1}{2}}$	6	23	(56)	875	0.863	0.886
3164.483	—	31591.62	$a^4H°_{4\frac{1}{2}} - 130_{3\frac{1}{2}}$	5	—	—	1188	(1.018)	0.97
3162.836	10	31608.08	$a^4F°_{3\frac{1}{2}} - 150_{3\frac{1}{2}}$	5	—	—	1338	(1.173)	1.107
3154.730	15	31689.29	$a^4H°_{4\frac{1}{2}} - 131_{2\frac{1}{2}}$						
3149.960	10	31737.28	$a^4F°_{2\frac{1}{2}} - 137_{2\frac{1}{2}}$	5	—	—	1194	(1.061)	1.100
3146.041	12	31776.81	$a^4H°_{3\frac{1}{2}} - 126_{2\frac{1}{2}}$	4	171	(85)	280	0.707	0.878
3141.849	12	31819.20	$a^4F°_{2\frac{1}{2}} - 138_{1\frac{1}{2}}$	5	321	(159)	1551	1.069	0.748
3140.975	10	31828.05	$1°_{2\frac{1}{2}} - 160_{1\frac{1}{2}}$	4	357	(175)	459	(0.982)	1.337
3133.619	10	31902.77	$a^4G°_{3\frac{1}{2}} - 151_{2\frac{1}{2}}$	5	408	(201)	2031	0.604	1.012
3129.297	—	31946.83	$a^2H°_{4\frac{1}{2}} - 154_{3\frac{1}{2}}$	—	157	(71)	—	(0.931)	1.088
3127.207	—	31968.18	$a^4F°_{3\frac{1}{2}} - 153_{3\frac{1}{2}}$	6	232	(810)	1056	1.174	0.943
3124.388	12	31997.02	$a^4H°_{3\frac{1}{2}} - 128_{3\frac{1}{2}}$	6	264	(923)	857	0.722	0.986
3122.962	20	32011.63	$a^4H°_{3\frac{1}{2}} - 129_{4\frac{1}{2}}$	5	256	(126)	1883	0.730	0.986
3121.01	10	32031.65	$1°_{2\frac{1}{2}} - 162_{3\frac{1}{2}}$	5	—	—	1243	(0.982)	1.056
3117.661	—	32066.06	$a^4F°_{1\frac{1}{2}} - 133_{1\frac{1}{2}}$	6	439	(659)	704	0.489	0.928
3114.068	10	32103.05	$a^4G°_{2\frac{1}{2}} - 153_{2\frac{1}{2}}$	5	340	(176)	1786	0.599	0.939
3112.087	10	32123.49	$a^4H°_{3\frac{1}{2}} - 130_{3\frac{1}{2}}$						
3111.831	20*d*	32126.13	$a^4G°_{3\frac{1}{2}} - 150_{3\frac{1}{2}}$	—	204	—	—	(0.911)	1.115
3110.022	15	32144.82	$a^4F°_{1\frac{1}{2}} - 134_{1\frac{1}{2}}$	6	521	(782)	757	0.492	1.013
3107.029	15	32175.78	$a^4F°_{1\frac{1}{2}} - 136_{2\frac{1}{2}}$	4	456	(229)	260	0.487	0.943
3102.666	15	32221.03	$a^4H°_{3\frac{1}{2}} - 131_{4\frac{1}{2}}$	6	370	(1296)	904	0.721	1.091
3101.691	10	32231.15	$a^2D°_{1\frac{1}{2}} - 159_{1\frac{1}{2}}$	6	387	(577)	—	(0.832)	1.219
3099.863	10	32250.16	$a^4G°_{4\frac{1}{2}} - 151_{2\frac{1}{2}}$	5	—	—	1400	(1.086)	1.00
3096.434	10	32285.87	$a^4G°_{3\frac{1}{2}} - 151_{3\frac{1}{2}}$	6	95	(331)	—	(0.911)	1.006
3088.473	20	32369.09	$a^4F°_{2\frac{1}{2}} - 142_{3\frac{1}{2}}$	6	15	(36)	1071	1.064	1.079
3083.300	—	32423.40	$a^2D°_{2\frac{1}{2}} - 156_{2\frac{1}{2}}$	6	108	(270)	—	1.087	0.979
3083.004	12	32426.51	$1°_{2\frac{1}{2}} - 164_{3\frac{1}{2}}$	5	202	(99)	—	(0.982)	1.184
3077.343	2	32486.16	$a^4G°_{3\frac{1}{2}} - 153_{3\frac{1}{2}}$	6	24	(83)	928	0.916	0.940
3057.642	10	32605.46	$a^4H°_{3\frac{1}{2}} - 135_{2\frac{1}{2}}$						
3054.997	—	32723.77	$a^2D°_{1\frac{1}{2}} - 160_{1\frac{1}{2}}$	6	520	—	1087	0.835	1.355
3051.796	10	32758.10	$a^4H°_{4\frac{1}{2}} - 140_{3\frac{1}{2}}$	—	—	—	1091	(1.018)	0.997
3050.989	10	32766.76	$a^4G°_{3\frac{1}{2}} - a153_{2\frac{1}{2}}$						
3049.095	20	32787.11	$a^2F°_{3\frac{1}{2}} - 123_{3\frac{1}{2}}$	?	—	—	905	(0.857)	0.871
3045.568	12	32825.08	$a^4H°_{4\frac{1}{2}} - 155_{3\frac{1}{2}}$	4	149	(78)	157	1.125	0.976
3043.068	12	32852.04	$a^4H°_{4\frac{1}{2}} - 141_{4\frac{1}{2}}$	6	70	(314)	1066	1.020	1.090
3038.600	12	32900.35	$a^4H°_{3\frac{1}{2}} - 137_{2\frac{1}{2}}$	6	396	(1387)	909	0.715	1.111
3035.542	10	32933.49	$a^4G°_{3\frac{1}{2}} - 154_{2\frac{1}{2}}$						
3034.069	15	32949.48	$a^2F°_{2\frac{1}{2}} - 150_{3\frac{1}{2}}$	5	—	—	1180	(1.132)	1.113
3031.701	10	32975.21	$a^2F°_{3\frac{1}{2}} - 124_{2\frac{1}{2}}$						
3028.580	12	33009.19	$a^4F°_{1\frac{1}{2}} - 142_{2\frac{1}{2}}$	5	593	(298)	1982	0.499	1.092
3024.669	10	33051.87	$a^2F°_{3\frac{1}{2}} - 125_{1\frac{1}{2}}$						
3022.097	12	33080.00	$a^4F°_{3\frac{1}{2}} - 147_{4\frac{1}{2}}$	—	—	—	1177	(1.061)	1.095
3019.418	—	33109.35	$a^2F°_{3\frac{1}{2}} - 151_{2\frac{1}{2}}$	6	119	(417)	1082	1.146	1.027
3017.47	4	33130.72	$a^2D°_{2\frac{1}{2}} - 158_{3\frac{1}{2}}$						
3017.122	12	33134.54	$a^2D°_{2\frac{1}{2}} - 159_{1\frac{1}{2}}$	4	—	(60)	919	(1.088)	1.202
3014.925	12	33149.94	$a^4G°_{3\frac{1}{2}} - a153_{2\frac{1}{2}}$						
3011.593	40	33195.37	$a^4H°_{4\frac{1}{2}} - 143_{4\frac{1}{2}}$	7b	—	(0)	1020	1.020	1.020
3006.005	2	33257.08	$a^4F°_{1\frac{1}{2}} - 144_{1\frac{1}{2}}$	4	1050	—	0	0.491	1.541
3004.649	2	33272.09	$a^2G°_{3\frac{1}{2}} - 161_{2\frac{1}{2}}$	4	177	(92)	541	0.982	1.159
3003.855	—	33280.88	$a^4G°_{4\frac{1}{2}} - 154_{3\frac{1}{2}}$	7b	—	(0)	1088	1.088	1.088
3001.264	12	33309.61	$a^2F°_{3\frac{1}{2}} - 153_{3\frac{1}{2}}$	6	189	(656)	1037	1.134	0.945
2995.270	10	33376.27	$a^4F°_{3\frac{1}{2}} - 156_{2\frac{1}{2}}$	5	194	(98)	1662	1.179	0.985
2989.912	—	33436.07	$a^2G°_{4\frac{1}{2}} - 163_{3\frac{1}{2}}$	4	199	(100)	488	0.982	1.181
2988.234	15	33454.85	$a^2F°_{3\frac{1}{2}} - 126_{2\frac{1}{2}}$	6	32	(160)	873	0.84	0.91
2981.362	5	33531.96	$a^4H°_{3\frac{1}{2}} - 142_{3\frac{1}{2}}$	4	376	(200)	—	(0.718)	1.094
2976.020	15	33592.15	$a^4F°_{3\frac{1}{2}} - 149_{3\frac{1}{2}}$	6	74	(185)	1016	1.053	0.979
2974.013	10	33614.82	$a^2F°_{2\frac{1}{2}} - 127_{2\frac{1}{2}}$	6	315	(785)	1012	0.853	1.168
2972.932	—	33627.04	$a^2D°_{2\frac{1}{2}} - 160_{1\frac{1}{2}}$	—	261	(137)	—	(1.088)	1.349
2968.685	6	33675.14	$a^2F°_{3\frac{1}{2}} - 128_{3\frac{1}{2}}$	5	122	(65)	1295	0.868	0.990
2965.501	8	33711.30	$a^4H°_{4\frac{1}{2}} - 147_{3\frac{1}{2}}$	4	—	—	748	(1.018)	1.095
2964.113	5	33727.08	$a^4H°_{3\frac{1}{2}} - 143_{4\frac{1}{2}}$	5	307	—	2094	0.707	1.014
2957.590	10	33801.46	$a^2F°_{3\frac{1}{2}} - 130_{3\frac{1}{2}}$	5	—	—	1153	0.857	0.942
2955.038	6	33830.66	$a^2D°_{2\frac{1}{2}} - 162_{3\frac{1}{2}}$	—	—	—	1044	(1.088)	1.075
2949.491	—	33894.27	$a^4G°_{2\frac{1}{2}} - 156_{2\frac{1}{2}}$	4	—	(0)	824	(0.911)	0.986
2949.069	10	33899.13	$a^2F°_{3\frac{1}{2}} - 131_{2\frac{1}{2}}$	5	229	(113)	1662	0.869	1.098
2946.235	—	33931.73	$a^2H°_{4\frac{1}{2}} - 162_{3\frac{1}{2}}$	—	118	(64)	—	(0.931)	1.049
2942.634	5	33973.25	$a^2F°_{3\frac{1}{2}} - a153_{2\frac{1}{2}}$	7b	—	(0)	1122	1.122	1.122
2940.589	—	33996.87	$a^4F°_{2\frac{1}{2}} - 150_{2\frac{1}{2}}$	6	30	(75)	1090	(1.061)	1.101
2938.106	5	34025.61	$a^4G°_{3\frac{1}{2}} - 157_{2\frac{1}{2}}$	4	240	(117)	308	0.909	1.149
2937.445	5	34033.26	$a^4D°_{1\frac{1}{2}} - 171_{1\frac{1}{2}}$	6	222	(335)	1062	1.170	0.948
2933.104	8	34083.63	$a^4F°_{4\frac{1}{2}} - 158_{3\frac{1}{2}}$	6	148	(517)	1130	(1.173)	1.025
2928.256	12*a*	34140.06	$a^2F°_{3\frac{1}{2}} - 154_{2\frac{1}{2}}$	6	42	(147)	1116	1.137	1.095
2920.935	5	34225.62	$a^2D°_{2\frac{1}{2}} - 164_{3\frac{1}{2}}$						
2920.372	5	34232.22	$a^4F°_{4\frac{1}{2}} - 149_{4\frac{1}{2}}$	—	495	(251)	—	(0.492)	0.987
2919.842	10	34238.43	$a^2F°_{2\frac{1}{2}} - 132_{3\frac{1}{2}}$	6	397	(993)	1052	0.854	1.251
2917.39	25*d*	34267.21	$a^2F°_{2\frac{1}{2}} - 133_{1\frac{1}{2}}$	4	—	—	768	(0.857)	0.916
2909.767	—	34356.97	$a^4F°_{3\frac{1}{2}} - 153_{3\frac{1}{2}}$	4	82	(41)	664	1.03	0.95
2908.359	12*a*	34373.61	$a^2F°_{2\frac{1}{2}} - 135_{2\frac{1}{2}}$	6	115	(288)	910	(0.857)	0.972
2904.254	—	34422.19	$a^4D°_{1\frac{1}{2}} - 173_{2\frac{1}{2}}$	7b?	—	(0)	1214	(1.167)	1.186
2903.565	—	34430.36	$1°_{2\frac{1}{2}} - 170_{2\frac{1}{2}}$	6	154	(384)	1054	0.977	1.131
2899.724	15	34475.96	$a^4H°_{3\frac{1}{2}} - 148_{2\frac{1}{2}}$	4	138	(70)	369	0.714	0.852
2892.175	6	34565.95	$a^4G°_{4\frac{1}{2}} - 158_{4\frac{1}{2}}$	5	—	—	1304	1.092	1.031
2886.248	6	34636.93	$a^4F°_{4\frac{1}{2}} - 150_{3\frac{1}{2}}$	5	603	(304)	2005	0.501	1.104
2884.295	12	34660.38	$a^2F°_{2\frac{1}{2}} - 138_{1\frac{1}{2}}$	5	119	(40)	—	(0.857)	0.738
2883.628	—	34668.40	$a^4F°_{3\frac{1}{2}} - 161_{2\frac{1}{2}}$	—	—	—	1190	(1.173)	1.16
2882.014	10	34687.81	$a^2D°_{1\frac{1}{2}} - 167_{1\frac{1}{2}}$	6	55	(83)	856	0.828	0.883
2879.533	6	34717.69	$a^2F°_{3\frac{1}{2}} - 156_{2\frac{1}{2}}$	5	149	(70)	1509	1.136	0.987
2876.421	10	34755.25	$a^4H°_{3\frac{1}{2}} - 149_{2\frac{1}{2}}$	4	258	(128)	46	0.705	0.963
2873.717	8	34787.95	$a^4H°_{4\frac{1}{2}} - 151_{3\frac{1}{2}}$	7b	—	—	1022	1.022	1.022
2868.678	8	34849.06	$a^2F°_{3\frac{1}{2}} - 157_{2\frac{1}{2}}$	7b	—	—	1090	1.132	1.149
2868.401	—	34852.42	$1°_{2\frac{1}{2}} - 173_{2\frac{1}{2}}$	6	209	(523)	1088	0.982	1.191
2866.412	—	34876.61	$a^2F°_{2\frac{1}{2}} - 139_{3\frac{1}{2}}$	6	288	(707)	996	0.849	1.137
2861.416	8	34937.50	$a^2D°_{2\frac{1}{2}} - 166_{2\frac{1}{2}}$	7b	—	(0)	1078	1.078	1.078
2857.494	5	34985.45	$a^4F°_{1\frac{1}{2}} - 152_{1\frac{1}{2}}$	6	731	(1094)	857	0.487	1.218
2856.131	8	35026.67	$a^2D°_{1\frac{1}{2}} - 168_{2\frac{1}{2}}$						
2841.814	—	35178.48	$a^4F°_{3\frac{1}{2}} - 164_{3\frac{1}{2}}$	7b	—	(0)	1190	1.190	1.190
2841.168	8	35186.47	$a^4G°_{3\frac{1}{2}} - 161_{2\frac{1}{2}}$	4	244	(122)	302	0.912	1.156
2839.243	8	35210.33	$a^2F°_{3\frac{1}{2}} - 142_{2\frac{1}{2}}$	6	235	(582)	971	0.850	1.085
2830.445	10	35319.76	$a^4H°_{3\frac{1}{2}} - 151_{4\frac{1}{2}}$	6	293	(1019)	860	0.710	1.003
2829.936	6	35326.12	$a^2D°_{1\frac{1}{2}} - 170_{2\frac{1}{2}}$	5	316	(160)	1606	0.817	1.133
2827.992	5*d*	35350.40	$a^4G°_{3\frac{1}{2}} - 163_{3\frac{1}{2}}$						
2822.035	10*d*	35425.02	$a^2F°_{3\frac{1}{2}} - 158_{4\frac{1}{2}}$	6	102	(357)	1095	1.146	1.044
2817.139	—	35486.58	$a^2G°_{3\frac{1}{2}} - 168_{2\frac{1}{2}}$	4	132	—	676	0.995	1.127
2807.825	—	35604.28	$a^4G°_{3\frac{1}{2}} - 165_{2\frac{1}{2}}$	6	63	(158)	631	0.600	0.663
2803.381	2*h*	35660.73	$a^4G°_{4\frac{1}{2}} - 164_{3\frac{1}{2}}$						
2803.381	2*h*	35660.73	$a^4F°_{1\frac{1}{2}} - a153_{2\frac{1}{2}}$						
2800.572	6	35696.49	$a^4G°_{4\frac{1}{2}} - 164_{4\frac{1}{2}}$	6	272	(943)	1037	0.904	1.176
2797.740	10	35732.62	$a^2F°_{2\frac{1}{2}} - 145_{1\frac{1}{2}}$	5	—	—	1034	(0.857)	0.739
2791.016	10	35818.71	$a^4H°_{4\frac{1}{2}} - 154_{3\frac{1}{2}}$	4	—	(0)	778	(1.018)	1.087
2785.463	—	25890.12	$a^4F°_{3\frac{1}{2}} - 166_{3\frac{1}{2}}$						
2784.978	8	35896.36	$a^4F°_{2\frac{1}{2}} - 157_{2\frac{1}{2}}$	6	92	(230)	1097	1.051	1.143
2783.054	10	35921.17	$a^2F°_{2\frac{1}{2}} - 147_{2\frac{1}{2}}$	5	250	(124)	1734	0.865	1.115
2765.127	10	36154.05	$a^2F°_{3\frac{1}{2}} - 148_{3\frac{1}{2}}$	4	—	—	855	0.855	0.855
2763.613	10	36173.85	$a^2F°_{3\frac{1}{2}} - 163_{2\frac{1}{2}}$						
2745.829	—	36408.13	$a^4G°_{3\frac{1}{2}} - 166_{2\frac{1}{2}}$	4	158	(78)	—	(0.911)	1.069
2743.94	3	36433.19	$a^2F°_{2\frac{1}{2}} - 149_{2\frac{1}{2}}$						
2737.416	8	36520.01	$a^2F°_{3\frac{1}{2}} - 164_{3\frac{1}{2}}$	6	45	(158)	1147	1.125	1.170
2727.600	—	36651.44	$a^2D°_{2\frac{1}{2}} - 173_{2\frac{1}{2}}$	—	101	—	—	(1.088)	1.189
2725.568	—	36678.76	$a^4G°_{2\frac{1}{2}} - 167_{1\frac{1}{2}}$	4	294	(146)	12	(0.601)	0.895
2704.503	—	36964.43	$a^4D°_{\frac{1}{2}} - 174_{1\frac{1}{2}}$	5	687	(347)	1260	0.23	0.92
2702.933	—	36985.90	$a^4F°_{3\frac{1}{2}} - 169_{3\frac{1}{2}}$	6	78	(273)	—	(1.173)	1.095
2700.605	—	37017.77	$a^4G°_{3\frac{1}{2}} - 168_{3\frac{1}{2}}$	6	509	(1280)	857	0.602	1.111
2695.207	6	37091.91	$a^4D°_{\frac{1}{2}} - 175_{1\frac{1}{2}}$						
2694.347	—	37103.75	$a^4H°_{4\frac{1}{2}} - 158_{4\frac{1}{2}}$	7b	—	—	1022	1.022	1.022

TABLE II.—*Continued.*

Wave-length	Arc int.	Wave number	Classification	Type	Sep.	p	n	g_1	g_2
2693.635	—	37113.55	$a^2D^\circ_{1\frac{1}{2}}-174_{1\frac{1}{2}}$	6	89	(134)	881	0.837	0.926
2693.111	—	37120.78	$a^4G^\circ_{2\frac{1}{2}}-169_{2\frac{1}{2}}$	—	483	(240)	—	(0.601)	1.084
2689.377	—	37172.31	$a^4F^\circ_{2\frac{1}{2}}-162_{2\frac{1}{2}}$	7b	—	—	1096	(1.061)	1.072
2688.329	6	37186.80	$a^2F^\circ_{2\frac{1}{2}}-152_{1\frac{1}{2}}$	4	366	(183)	311	0.855	1.221
2678.938	5	37317.15	$a^4G^\circ_{2\frac{1}{2}}-170_{2\frac{1}{2}}$	6	543	(1351)	860	0.589	1.132
2656.272	—	37635.56	$a^4H^\circ_{3\frac{1}{2}}-158_{3\frac{1}{2}}$	6	308	(1077)	—	(0.718)	1.026
2640.393	—	37861.88	$a^2F^\circ_{2\frac{1}{2}}-a153_{2\frac{1}{2}}$	6	270	(671)	—	(0.857)	1.127
2628.816	8	38028.61	$a^2F^\circ_{2\frac{1}{2}}-154_{2\frac{1}{2}}$	5	229	(113)	1666	0.868	1.097
2622.354	—	38122.31	$a^4G^\circ_{3\frac{1}{2}}-173_{2\frac{1}{2}}$	—	277	(135)	—	(0.911)	1.188
2615.353	5	38224.36	$a^2F^\circ_{2\frac{1}{2}}-168_{2\frac{1}{2}}$						
2608.327	5	38327.31	$a^2F^\circ_{2\frac{1}{2}}-160_{2\frac{1}{2}}$	6	(42)	(148)	1104	1.125	1.083
2595.033	7	38523.65	$a^2F^\circ_{2\frac{1}{2}}-170_{2\frac{1}{2}}$	7b	—	—	1115	(1.132)	1.139
2580.700	8	38737.59	$a^2F^\circ_{2\frac{1}{2}}-157_{2\frac{1}{2}}$	6	300	(751)	1000	0.852	1.152
2566.905	—	38945.75	$a^2F^\circ_{2\frac{1}{2}}-173_{2\frac{1}{2}}$	4	—	—	1008	(1.132)	1.182
2561.937	10	39021.28	$a^4H^\circ_{3\frac{1}{2}}-165_{2\frac{1}{2}}$	5	—	—	788	(0.718)	0.690
2556.480	—	39104.56	$a^4G^\circ_{2\frac{1}{2}}-174_{1\frac{1}{2}}$	4	322	(157)	122	0.605	0.927
2548.159	8s	39232.25	$a^4G^\circ_{3\frac{1}{2}}-175_{1\frac{1}{2}}$	4	361	(176)	80	0.592	0.953
2542.642	8s	39317.37	$a^2F^\circ_{2\frac{1}{2}}-159_{1\frac{1}{2}}$	4	354	(178)	322	0.851	1.205
2538.940	—	39374.69	$a^4F^\circ_{3\frac{1}{2}}-169_{2\frac{1}{2}}$	7b	—	(0)	1107	(1.061)	1.075
2534.604	—	39442.04	$a^4H^\circ_{4\frac{1}{2}}-166_{3\frac{1}{2}}$	4	361	(178)	180	0.719	1.080
2526.342	—	39571.03	$a^4F^\circ_{2\frac{1}{2}}-170_{2\frac{1}{2}}$	6	70	(174)	1097	1.062	1.132
2511.181	5	39809.92	$a^2F^\circ_{2\frac{1}{2}}-160_{2\frac{1}{2}}$	4	488	(238)	112	0.851	1.339
2509.97	8	39829.12	$a^4G^\circ_{3\frac{1}{2}}-176_{1\frac{1}{2}}$	4	403	(200)	30	0.592	0.995
2505.615	10	39898.34	$a^2F^\circ_{2\frac{1}{2}}-161_{2\frac{1}{2}}$	6	303	(757)	1008	0.860	1.163
2499.679	—	39993.09	$a^4F^\circ_{2\frac{1}{2}}-173_{2\frac{1}{2}}$	6	128	(319)	—	(1.061)	1.189
2498.863	10	40006.06	$a^4H^\circ_{4\frac{1}{2}}-169_{3\frac{1}{2}}$	4	—	(0)	844	(1.018)	1.069
2498.402	8	40013.52	$a^2F^\circ_{2\frac{1}{2}}-162_{2\frac{1}{2}}$	5	212	(104)	1623	0.88	1.09
2495.353	8	40062.41	$a^2F^\circ_{2\frac{1}{2}}-163_{2\frac{1}{2}}$						
2473.98	—	40408.49	$a^4F^\circ_{2\frac{1}{2}}-164_{2\frac{1}{2}}$						
2456.292	6	40699.45	$a^2F^\circ_{2\frac{1}{2}}-165_{2\frac{1}{2}}$	6	182	(465)	756	0.853	0.671
2431.16	4	41120.14	$a^2F^\circ_{2\frac{1}{2}}-166_{2\frac{1}{2}}$	6	218	(547)	970	0.86	1.08
2393.113	5	41773.84	$a^2F^\circ_{2\frac{1}{2}}-167_{1\frac{1}{2}}$	7b	—	—	826	(0.857)	0.878
2373.846	3	42112.86	$a^2F^\circ_{2\frac{1}{2}}-168_{2\frac{1}{2}}$	6	256	(639)	1000	0.862	1.118
2368.051	5	42215.91	$a^2F^\circ_{2\frac{1}{2}}-169_{2\frac{1}{2}}$	5	222	(107)	1638	0.859	1.081
2355.251	4	42445.32	$a^2F^\circ_{2\frac{1}{2}}-171_{1\frac{1}{2}}$	7b	—	—	761	(0.857)	0.921
2333.864	6	42834.26	$a^2F^\circ_{2\frac{1}{2}}-173_{2\frac{1}{2}}$						

The spectrograms were measured in both directions with an automatic comparator.[7] The final g values reduced from the various plates were usually found to be mutually consistent to within ± 0.003 unit.

RESULTS

On account of the great complexity of the Th II spectrum, the necessary technique of reduction of its Zeeman patterns is somewhat different from that which can be used with simple patterns which do not overlap. The g values can usually be determined best by using only the most completely resolved components to obtain the fundamental separation. For this reason, detailed measurements on the components of all of the Zeeman patterns are not given in Tables I and II, but a shorthand notation is used which has been explained in a previous paper.[5]

Table I contains 523 lines classified in Group A, of which resolved Zeeman patterns have been measured for 356. The first column contains the wave-length of the line as given in the *M.I.T. Wavelength Tables*, while the second gives the arc intensity from the same tables. The third column gives the wave number calculated from the tabular wave-length, followed by the classification which we have assigned to the line. The column headed "Type" gives the Zeeman pattern type in the shorthand notation described previously,[5] as follows:

Type 1: Odd multiplicity, $J_1>J_2$, $g_1<g_2$, shade out.

Type 2: Odd multiplicity, $J_1>J_2$, $g_1>g_2$, shade in.

Type 3: Odd multiplicity, $J_1=J_2$, $g_1\neq g_2$, symmetrical.

Type 4: Even multiplicity, $J_1>J_2$, $g_1<g_2$, shade out.

Type 5: Even multiplicity, $J_1>J_2$, $g_1>g_2$, shade in.

Type 6: Even multiplicity, $J_1=J_2$, $g_1\neq g_2$, symmetrical.

Type 7a: Limiting cases of types 1 and 2, $J_1>J_2=0$, $g_1\gtrless g_2$, triplet.

Type 7b: Limiting cases of types 1, 2, 3, 4, 5, 6, $g_1=g_2$ triplet. Any multiplicity and all singlet combinations.

The next three columns give, respectively, the fundamental separation Δg between the components of the pattern, the displacement from the 0 field position of the strongest p component, and the same for the strongest n component, all in terms of thousandths of a Lorentz unit. The last two columns give, respectively, the observed g values for the two terms from which the line originates. g values in parentheses have been assumed from the average value determined for the involved level, thus making possible calculation of g values for the second term in each case

[7] G. R. Harrison, J. Opt. Soc. Am. **25**, 169 (1935); Rev. Sci. Inst. **9**, 15 (1938); G. R. Harrison and J. P. Molnar, J. Opt. Soc. Am. **30**, 343 (1940).

TABLE III. Th II.

Configuration	Term	Wave Number	g_{LS}	$g_{Meas.}$		Configuration	Term	Wave Number	g_{LS}	$g_{Meas.}$	
Low even levels, group A											
$6d^2 \cdot 7s$	$a^4F_{1\frac{1}{2}}$	0.00	0.400	0.639	±0.002	$6d^2 \cdot 7s$	$a^2F_{2\frac{1}{2}}$	8605.85	0.857	0.986	±0.003
$6d^2 \cdot 7s$	$a^4F_{2\frac{1}{2}}$	1521.91	1.029	1.076	±0.003	$6d^2 \cdot 7s$	$a^4P_{2\frac{1}{2}}$	9061.08	1.600	1.419	±0.002
$6d^3$	$b^4F_{1\frac{1}{2}}$	1859.94	0.400	0.586	±0.003	$6d^2 \cdot 7s$	$b^2D_{2\frac{1}{2}}$	9400.94	1.200	1.034	±0.003
$6d^3$	$b^4F_{2\frac{1}{2}}$	4113.36	1.029	1.163	±0.003	$6d^2 \cdot 7s$	$a^2G_{3\frac{1}{2}}$	9711.95	0.889	0.953	±0.002
$6d^2 \cdot 7s$	$a^4F_{3\frac{1}{2}}$	4146.57	1.238	1.232	±0.003	$6d^2 \cdot 7s$	$a^2P_{1\frac{1}{2}}$	12219.95	1.333	0.977	±0.004
$6d^2 \cdot 7s$	$a^4F_{4\frac{1}{2}}$	6213.55	1.333	1.312	±0.001	$6d^3$	$b^4F_{4\frac{1}{2}}$	13248.68	1.333	1.242	±0.001
$6d^2 \cdot 7s$	$a^4P_{\frac{1}{2}}$	6244.30	2.667	2.112	±0.005	$6d \cdot 7s^2$	$a^2D_{2\frac{1}{2}}$	13250.50	1.200	1.245	±0.003
$6d \cdot 7s^2$	$a^2D_{1\frac{1}{2}}$	7001.42	0.800	0.800	±0.003	$6d^3$	$b^4P_{\frac{1}{2}}$	14349.49	2.667	2.555	±0.006
$6d^2 \cdot 7s$	$a^2P_{\frac{1}{2}}$	7828.61	0.667	1.254	±0.004	$6d^3$	$b^4P_{1\frac{1}{2}}$	15236.64	1.733	1.592	±0.005
$6d^2 \cdot 7s$	$a^4P_{1\frac{1}{2}}$	8018.19	1.733	1.608	±0.003	$6d^3$	$a^2H_{4\frac{1}{2}}$	15305.06	0.909	1.006	±0.003
$6d^2 \cdot 7s$	$b^2D_{1\frac{1}{2}}$	8460.39	0.800	0.968	±0.004						
High odd levels, group A											
$5f6d7s$	$z^2P^\circ_{1\frac{1}{2}}$	17121.63	1.333	1.279		$6d^2 \cdot 7p$	$z^4G^\circ_{4\frac{1}{2}}$	36193.70	1.172	1.149	
$5f6d7s$	$z^2D^\circ_{1\frac{1}{2}}$	18214.47	0.800	0.876		$6d7s7p$	$y^4F^\circ_{1\frac{1}{2}}$	36390.49	0.400	0.829	
$6d^2 \cdot 7p$	$z^4F^\circ_{1\frac{1}{2}}$	19050.87	0.400	0.888			$f^2D^\circ_{1\frac{1}{2}}$	36444.81	0.800	1.182	
$5f6d7s$	$z^2D^\circ_{2\frac{1}{2}}$	19248.32	1.200	0.931			$f^2P^\circ_{1\frac{1}{2}}$	36581.57	1.333	1.107	
$5f6d7s$	$z^2F^\circ_{3\frac{1}{2}}$	20080.68	1.143	1.142		$6d^2 \cdot 7p$	$z^4G^\circ_{3\frac{1}{2}}$	36583.83	0.984	1.140	
$5f6d7s$	$z^2F^\circ_{2\frac{1}{2}}$	21297.45	0.857	0.767		$6d^2 \cdot 7p$	$z^4G^\circ_{2\frac{1}{2}}$	36687.99	0.571	1.049	
$5f6d7s$	$z^2G^\circ_{4\frac{1}{2}}$	22139.64	1.111	1.090		$6d^2 \cdot 7p$	$y^4D^\circ_{\frac{1}{2}}$	37130.35	0.000	0.521	
$5f6d7s$	$z^2H^\circ_{4\frac{1}{2}}$	22642.20	0.909	1.043		$6d^2 \cdot 7p$	$y^4D^\circ_{1\frac{1}{2}}$	37601.71	1.200	1.267	
	$y^2D^\circ_{1\frac{1}{2}}$	23012.03	0.800	1.017		$6d^2 \cdot 7p$	$z^2S^\circ_{\frac{1}{2}}$	37608.01	2.000	2.239	
	$y^2P^\circ_{1\frac{1}{2}}$	23372.57	1.333	1.067			$v^2P^\circ_{\frac{1}{2}}$	37716.37	0.667	0.690	
$6d^2 \cdot 7p$	$y^2G^\circ_{4\frac{1}{2}}$	23730.81	1.111	1.186			$x^2G^\circ_{3\frac{1}{2}}$	37757.29	0.889	1.118	
	$x^2P^\circ_{1\frac{1}{2}}$	24132.05	1.333	1.429		$6d7s7p$	$y^4F^\circ_{2\frac{1}{2}}$	37846.15	1.029	1.165	
	$x^2D^\circ_{1\frac{1}{2}}$	24414.60	0.800	1.105		$6d^2 \cdot 7p$	$z^4P^\circ_{1\frac{1}{2}}$	38436.16	1.733	1.419	
	$y^2D^\circ_{2\frac{1}{2}}$	24463.86	1.200	1.396			$r^2D^\circ_{2\frac{1}{2}}$	38493.72	1.200	1.217	
	$y^2F^\circ_{2\frac{1}{2}}$	24873.99	0.857	1.081			$u^2F^\circ_{2\frac{1}{2}}$	38581.62	0.857	1.105	
$5f6d7s$	$z^2G^\circ_{2\frac{1}{2}}$	24982.42	0.889	0.990		$6d7s7p$	$z^4D^\circ_{3\frac{1}{2}}$	39396.54	1.429	1.131	
	$w^2D^\circ_{1\frac{1}{2}}$	25188.08	0.800	0.937		$6d^2 \cdot 7p$	$x^2G^\circ_{4\frac{1}{2}}$	39443.02	1.111	1.145	
$5f6d7s$	$z^2P^\circ_{\frac{1}{2}}$	25266.58	0.667	0.725		$6d^2 \cdot 7p$	$z^4G^\circ_{5\frac{1}{2}}$	39606.17	1.273	1.259	
	$x^2D^\circ_{2\frac{1}{2}}$	25440.26	1.200	1.138		$6d^2 \cdot 7p$	$z^4P^\circ_{2\frac{1}{2}}$	39861.63	1.600	1.172	
	$w^2D^\circ_{2\frac{1}{2}}$	26424.53	1.200	1.169			$s^2D^\circ_{1\frac{1}{2}}$	40472.42	0.800	1.249	
	$y^2P^\circ_{\frac{1}{2}}$	26626.45	0.667	0.614			$t^2F^\circ_{2\frac{1}{2}}$	40654.54	0.857	0.943	
	$v^2D^\circ_{1\frac{1}{2}}$	27403.17	0.800	1.002		$6d7s7p$	$y^4F^\circ_{3\frac{1}{2}}$	40707.40	1.238	1.073	
$6d^2 \cdot 7p$	$z^4F^\circ_{2\frac{1}{2}}$	28243.84	1.029	0.922		$6d^2 \cdot 7p$	$x^4D^\circ_{\frac{1}{2}}$	40825.58	0.000	0.261	
	$w^2P^\circ_{1\frac{1}{2}}$	28720.86	1.333	1.162		$6d^2 \cdot 7p$	$z^4S^\circ_{1\frac{1}{2}}$	42112.93	2.000	1.467	
	$x^2F^\circ_{2\frac{1}{2}}$	29095.46	0.857	0.998		$6d^2 \cdot 7p$	$y^4D^\circ_{2\frac{1}{2}}$	42219.77	1.371	1.168	
	$v^2P^\circ_{1\frac{1}{2}}$	29720.42	1.333	0.990		$6d^2 \cdot 7p$	$z^4F^\circ_{4\frac{1}{2}}$	42318.99	1.333	1.165	
	$x^2P^\circ_{\frac{1}{2}}$	30564.59	0.667	0.553		$6d^2 \cdot 7p$	$x^4D^\circ_{1\frac{1}{2}}$	42418.19	1.200	1.304	
$6d7s7p$	$z^4D^\circ_{2\frac{1}{2}}$	30972.18	1.371	1.217		$6d^2 \cdot 7p$	$y^4D^\circ_{3\frac{1}{2}}$	42944.46	1.429	1.246	
	$y^2G^\circ_{3\frac{1}{2}}$	30994.30	0.889	1.199		$6d7s7p$	$y^4P^\circ_{1\frac{1}{2}}$	43287.63	1.733	1.564	
$6d7s7p$	$z^4D^\circ_{1\frac{1}{2}}$	31353.12	1.200	0.863		$6d^2 \cdot 7p$	$x^4D^\circ_{2\frac{1}{2}}$	43382.76	1.371	1.203	
$6d7s7p$	$z^4D^\circ_{\frac{1}{2}}$	31625.75	0.000	0.344		$6d7s7p$	$y^4P^\circ_{\frac{1}{2}}$	43744.06	2.667	2.219	
	$y^2F^\circ_{3\frac{1}{2}}$	31800.21	1.143	1.168			$x^2F^\circ_{3\frac{1}{2}}$	44650.52	1.143	1.234	
	$v^2D^\circ_{2\frac{1}{2}}$	31810.57	1.200	1.118			$q^2D^\circ_{2\frac{1}{2}}$	44821.86	1.200	0.999	
	$u^2D^\circ_{1\frac{1}{2}}$	31928.77	0.800	0.891		$6d7s7p$	$y^4P^\circ_{2\frac{1}{2}}$	45221.48	1.600	1.347	
	$u^2D^\circ_{2\frac{1}{2}}$	32850.04	1.200	1.093		$6d^2 \cdot 7p$	$y^2H^\circ_{4\frac{1}{2}}$	45489.12	0.909	1.089	
	$t^2D^\circ_{2\frac{1}{2}}$	32933.45	1.200	1.113		$6d^2 \cdot 7p$	$x^4D^\circ_{3\frac{1}{2}}$	45689.25	1.429	1.261	
$6d^2 \cdot 7p$	$z^4F^\circ_{3\frac{1}{2}}$	32957.41	1.238	1.072			$s^2F^\circ_{2\frac{1}{2}}$	46155.57	0.857	1.152	
	$u^2P^\circ_{1\frac{1}{2}}$	33215.78	1.333	1.036		$6d7s7p$	$y^4F^\circ_{4\frac{1}{2}}$	46368.03	1.333	1.088	
	$w^2F^\circ_{2\frac{1}{2}}$	33355.22	0.857	0.952			$s^2P^\circ_{1\frac{1}{2}}$	46423.77	1.333	1.118	
	$s^2D^\circ_{2\frac{1}{2}}$	34212.03	1.200	1.148			$p^2D^\circ_{2\frac{1}{2}}$	49289.44	1.200	1.208	
$6d^2 \cdot 7p$	$z^4P^\circ_{\frac{1}{2}}$	34330.47	2.667	1.503							
	$v^2F^\circ_{2\frac{1}{2}}$	35156.97	0.857	1.079							
	$w^2P^\circ_{\frac{1}{2}}$	35199.03	0.667	0.972							

from unresolved, poorly defined, or incomplete patterns.

Table II contains 580 lines which have been classified in Group B, resolved Zeeman patterns having been measured for 382 lines. The notation used is identical with that of Table I.

TABLE IV. Th II.

Configuration	Term	Wave number	g_{LS}	$g_{Meas.}$	Configuration	Term	Wave number	g_{LS}	$g_{Meas.}$
				Low odd levels, group B					
$5f\cdot7s^2$	$a^2F^\circ_{2\frac{1}{2}}$	0.00	0.857	0.856	$5f6d7s$	$a^2H^\circ_{4\frac{1}{2}}$	6081.80	0.909	0.931
$5f6d7s$	$a^4H^\circ_{3\frac{1}{2}}$	1678.09	0.667	0.718	$5f6d7s$	$b^2F^\circ_{2\frac{1}{2}}$	6182.87	0.857	1.088
$5f6d7s$	$a^4F^\circ_{1\frac{1}{2}}$	2201.15	0.400	0.492	$5f6d7s$	$a^2G^\circ_{3\frac{1}{2}}$	6626.32	0.889	0.983
$5f6d7s$	$a^4H^\circ_{4\frac{1}{2}}$	2209.90	0.970	1.018	$5f6d7s$	$a^2D^\circ_{1\frac{1}{2}}$	7086.14	0.800	0.832
$5f6d7s$	$a^4F^\circ_{2\frac{1}{2}}$	2841.22	1.029	1.061	$5f6d7s$	$a^4D^\circ_{\frac{1}{2}}$	7235.26	0.000	0.255
$5f\cdot7s^2$	$a^2F^\circ_{3\frac{1}{2}}$	3888.56	1.143	1.132	....	$1^\circ_{2\frac{1}{2}}$	7981.89		0.982
$5f6d7s$	$a^4G^\circ_{2\frac{1}{2}}$	4712.00	0.984	0.911	$5f6d7s$	$a^4D^\circ_{1\frac{1}{2}}$	8412.13	1.200	1.167
$5f6d7s$	$a^4G^\circ_{4\frac{1}{2}}$	4747.75	1.172	1.086	....	$2^\circ_{4\frac{1}{2}}$	9785.32		0.791
$5f6d7s$	$a^4G^\circ_{2\frac{1}{2}}$	5095.13	0.571	0.601	....	$3^\circ_{3\frac{1}{2}}$	10300.77		0.862
$5f6d7s$	$a^4F^\circ_{3\frac{1}{2}}$	5230.01	1.238	1.173	....	$4^\circ_{1\frac{1}{2}}$	10654.49		1.366
$5f6d7s$	$a^4H^\circ_{5\frac{1}{2}}$	5698.81	1.133	1.128					
				Even levels—group B					
	$z^4G_{2\frac{1}{2}}$	21998.35	0.571	0.776		$131_{3\frac{1}{2}}$	33899.14		1.088
	$z^4G_{3\frac{1}{2}}$	22766.90	0.984	1.032		$132_{2\frac{1}{2}}$	34238.42		1.255
	$z^4F_{1\frac{1}{2}}$	23141.03	0.400	0.625		$133_{1\frac{1}{2}}$	34267.21		0.935
	$y^4F_{1\frac{1}{2}}$	23520.95	0.400	0.717		$134_{3\frac{1}{2}}$	34345.95		1.013
	$z^4F_{2\frac{1}{2}}$	24333.39	1.029	0.987		$135_{2\frac{1}{2}}$	34373.58		0.967
	$101_{2\frac{1}{2}}$	24473.24		0.855		$136_{\frac{1}{2}}$	34376.92		0.947
	$z^4H_{4\frac{1}{2}}$	25024.90	0.970	1.030		$137_{3\frac{1}{2}}$	34578.46		1.114
	$z^2H_{4\frac{1}{2}}$	25962.48	0.909	1.035		$138_{1\frac{1}{2}}$	34660.42		0.739
	$y^4G_{2\frac{1}{2}}$	26769.04	0.571	0.781		$139_{2\frac{1}{2}}$	34876.61		1.140
	$102_{2\frac{1}{2}}$	27263.96		0.948		$140_{3\frac{1}{2}}$	34968.07		0.979
	$z^4G_{4\frac{1}{2}}$	27282.79	1.172	1.222		$141_{4\frac{1}{2}}$	35062.00		1.100
	$103_{3\frac{1}{2}}$	28086.48		1.024		$142_{2\frac{1}{2}}$	35210.30		1.090
	$z^2I_{5\frac{1}{2}}$	28130.61	0.923	0.826		$143_{4\frac{1}{2}}$	35405.18		1.024
	$y^4G_{3\frac{1}{2}}$	28245.91	0.984	0.904		$144_{\frac{1}{2}}$	35458.23		1.542
	$104_{1\frac{1}{2}}$	28469.32		0.874		$145_{1\frac{1}{2}}$	35732.65		0.738
	$105_{2\frac{1}{2}}$	28719.14		1.051		$146_{1\frac{1}{2}}$	35787.86		0.705
	$z^4H_{3\frac{1}{2}}$	29146.97	0.667	0.830		$147_{3\frac{1}{2}}$	35921.23		1.106
	$106_{2\frac{1}{2}}$	29240.65		1.031		$148_{2\frac{1}{2}}$	36154.05		0.856
	$107_{1\frac{1}{2}}$	29529.98		0.823		$149_{2\frac{1}{2}}$	36433.30		0.988
	$108_{2\frac{1}{2}}$	29684.28		0.986		$150_{2\frac{1}{2}}$	36838.09		1.101
	$109_{4\frac{1}{2}}$	29780.00		0.938		$151_{3\frac{1}{2}}$	36997.91		1.010
	$110_{3\frac{1}{2}}$	29789.05		1.047		$152_{1\frac{1}{2}}$	37186.61		1.220
	$111_{2\frac{1}{2}}$	30053.34		1.003		$153_{3\frac{1}{2}}$	37198.19		0.940
	$112_{4\frac{1}{2}}$	30064.08		1.069		$a153_{2\frac{1}{2}}$	37861.89		1.126
	$z^4H_{5\frac{1}{2}}$	30171.47	1.133	0.998		$154_{3\frac{1}{2}}$	38028.62		1.080
	$z^4F_{3\frac{1}{2}}$	30236.31	1.238	0.950		$155_{4\frac{1}{2}}$	38523.89		0.978
	$z^4D_{\frac{1}{2}}$	30935.41	0.000	0.265		$156_{2\frac{1}{2}}$	38606.27		0.982
	$y^4H_{4\frac{1}{2}}$	30965.91	0.970	1.054		$157_{2\frac{1}{2}}$	38737.61		1.153
	$113_{4\frac{1}{2}}$	31055.35		0.826		$158_{3\frac{1}{2}}$	39313.65		1.026
	$114_{2\frac{1}{2}}$	31251.07		0.954		$159_{1\frac{1}{2}}$	39317.36		1.211
	$115_{3\frac{1}{2}}$	31388.60		0.983		$160_{1\frac{1}{2}}$	39809.92		1.342
	$116_{\frac{1}{2}}$	31550.61		1.210		$161_{2\frac{1}{2}}$	39898.41		1.158
	$117_{2\frac{1}{2}}$	31575.47		0.887		$162_{3\frac{1}{2}}$	40013.53		1.058
	$y^4G_{4\frac{1}{2}}$	31635.14	1.172	1.035		$163_{2\frac{1}{2}}$	40062.39		1.182
	$118_{5\frac{1}{2}}$	31819.82		0.890		$164_{3\frac{1}{2}}$	40408.49		1.181
	$119_{1\frac{1}{2}}$	31838.40		1.615		$165_{2\frac{1}{2}}$	40699.41		0.674
	$120_{3\frac{1}{2}}$	32319.00		1.022		$166_{2\frac{1}{2}}$	41120.25		1.075
	$121_{\frac{1}{2}}$	32322.24		0.737		$167_{1\frac{1}{2}}$	41773.89		0.891
	$122_{4\frac{1}{2}}$	32573.07		0.999		$168_{2\frac{1}{2}}$	42112.90		1.112
	$123_{2\frac{1}{2}}$	32787.10		0.881		$169_{3\frac{1}{2}}$	42215.91		1.081
	$124_{2\frac{1}{2}}$	32975.19		1.048		$170_{2\frac{1}{2}}$	42412.25		1.143
	$125_{1\frac{1}{2}}$	33051.91		1.003		$171_{1\frac{1}{2}}$	42445.35		0.943
	$126_{2\frac{1}{2}}$	33454.80		0.893		$172_{1\frac{1}{2}}$	42658.47		
	$127_{2\frac{1}{2}}$	33614.82		1.172		$173_{2\frac{1}{2}}$	42834.29		1.189
	$128_{3\frac{1}{2}}$	33675.11		0.981		$174_{1\frac{1}{2}}$	44199.7		0.922
	$129_{4\frac{1}{2}}$	33689.68		0.979		$175_{1\frac{1}{2}}$	44327.30		0.956
	$130_{3\frac{1}{2}}$	33801.52		0.949		$176_{1\frac{1}{2}}$	44924.25		1.003

TABLE V. Tests of g sums (none complete).

Term	Level	g_{LS}	$g_{Meas.}$	Term	Level	g_{LS}	$g_{Meas.}$	Term	Level	g_{LS}	$g_{Meas.}$
$a^4P_{\frac{1}{2}}$	6244	2.667	2.112	$a^4F_{2\frac{1}{2}}$	1521	1.029	1.076	$z^2P^\circ_{\frac{1}{2}}$		0.667	0.725
$a^2P_{\frac{1}{2}}$	7828	0.667	1.254	$b^4F_{2\frac{1}{2}}$	4113	1.029	1.163	$y^2P^\circ_{\frac{1}{2}}$		0.667	0.614
$b^4P_{\frac{1}{2}}$	14349	2.667	2.555	$a^2F_{2\frac{1}{2}}$	8605	0.857	0.986	$x^2P^\circ_{\frac{1}{2}}$		0.667	0.553
				$a^4P_{2\frac{1}{2}}$	9061	1.600	1.419	$z^4D^\circ_{\frac{1}{2}}$		0.000	0.344
Sum:		6.001	5.921	$b^2D_{2\frac{1}{2}}$	9400	1.200	1.034	$z^4P^\circ_{\frac{1}{2}}$		2.667	1.503
				$a^2D_{2\frac{1}{2}}$	13250	1.200	1.245	$w^2P^\circ_{\frac{1}{2}}$		0.667	0.972
$a^4F_{1\frac{1}{2}}$	0	0.400	0.639					$y^4D^\circ_{\frac{1}{2}}$		0.000	0.521
$b^4F_{1\frac{1}{2}}$	1859	0.400	0.586	Sum:		6.915	6.923	$z^2S^\circ_{\frac{1}{2}}$		2.000	2.239
$a^2D_{1\frac{1}{2}}$	7001	0.800	0.800					$v^2P^\circ_{\frac{1}{2}}$		0.667	0.690
$a^4P_{1\frac{1}{2}}$	8018	1.733	1.608	$a^4F_{3\frac{1}{2}}$	4146	1.238	1.232	$x^4D^\circ_{\frac{1}{2}}$		0.000	0.261
$b^2D_{1\frac{1}{2}}$	8460	0.800	0.968	$a^2G_{3\frac{1}{2}}$	9711	0.889	0.953	$y^4P^\circ_{\frac{1}{2}}$		2.667	2.219
$a^2P_{1\frac{1}{2}}$	12219	1.333	0.977								
$b^4P_{1\frac{1}{2}}$	15236	1.733	1.592	Sum:		2.127	2.185	Sum:		10.669	10.641
Sum:		7.199	7.170	$a^4F_{4\frac{1}{2}}$	6213	1.333	1.312				
				$b^4F_{4\frac{1}{2}}$	13248	1.333	1.242				
				$a^2H_{4\frac{1}{2}}$	15305	0.909	1.006				
				Sum:		3.575	3.560				

Table III describes the energy levels which have been found in Group A. The first column gives the electron configuration assignment, which appears to be fairly definite for most of the low even levels. The second column gives the term assignment, followed by the wave number of the level in reciprocal centimeters relative to $a^4F_{1\frac{1}{2}}$ as 0.00. The fourth column gives the calculated g value for a term of the type listed for pure Russell-Saunders coupling, while the fifth column gives the g value actually observed, followed in a few cases by the average deviation of g as determined from different spectrum lines, where results from a large number of lines could be averaged. Where no probable error is given, it is considered to be less than ± 0.01, except in a few isolated cases where results were taken from a single only partially resolved pattern.

Table IV contains the levels assigned to Group B, arranged similiarly to Table III, where the available data are known. Levels to which no definite quantum assignments could be given are numbered, the subscript giving the proper inner quantum number as determined from Zeeman patterns.

QUANTUM ASSIGNMENTS

The spectrum of Th II can be expected to be somewhat similar to those of Ac I (which has not been analyzed), La I, Lu I, Y I, and Sc I. All of these mark the beginning of long periods of the Periodic Table, in which a d shell is being filled. They have 3-electron spectra formed by the addition of an electron to the two valence electrons which give the comparatively simple spectra of the alkaline-earths. However, the Th II spectrum can be expected to show added complexity introduced by the relative lowness of terms arising from electrons in the $5f$ shell, similar to that introduced by the $4f$ shell in the rare earths. Low-lying configurations to be expected are $6d7s^2$, giving rise to ^2D, $6d^27s$, giving rise to $^{4,2}(FP)$, $^2(GDS)$, and $6d^3$, giving rise to $^4(FP)$, $^2(HGFDP)$, ^2D. These terms should combine strongly with odd levels arising from $6d^27p$, $^{4,2}(GFD)^\circ$, $^{4,2}(DPS)^\circ$, $^2(HGF)^\circ$, $^2(FDP)^\circ$, $^2P^\circ$, from $6d7s7p$, $^{4,2}(FDP)^\circ$, $^2(FDP)^\circ$, and from fds. A few more than half of these terms have been found in Group A.

Group B contains terms expected to arise from $5f7s^2$, $^2F^\circ$, and $5f6d7s$, $^{4,2}(HGFDP)^\circ$, $^2(HGFDP)^\circ$. A large proportion of these terms have been identified. Even terms in Group B should be $5f7s7p$, $^{4,2}(GFD)$, $^2(GFD)$, and $5f6d7p$, $^{4,2}(IH_2G_3F_3D_3P_2S)$, $^2(IH_2G_3F_3D_3P_2S)$.

Since so many of the levels belonging to Groups A and B have been found, and there is still a large remainder of unclassified Th II lines, it appears probable that a third energy system exists.

The lowest level of Th II is $a^4F_{1\frac{1}{2}}$ arising from the $6d^27s$ configuration. It is very strongly perturbed, however, by $b^4F_{1\frac{1}{2}}$ from $6d^3$, which lies only 1860 wave numbers away, and since the g values of both of these terms are increased by an average of 50 percent, it appears possible that

an undiscovered term having $J=1\frac{1}{2}$ lies closer than $a^2D_{1\frac{1}{2}}$, which is 7000 wave numbers away from the lowest term and appears to be unperturbed. Even so, the g sums for known $1\frac{1}{2}$ levels are nearly correct. Detailed considerations of this sort must wait, however, until the spectrum has been more completely analyzed.

Table V contains tests of the g sum rule in a few of the cases where a sufficient number of related levels have been determined to make such a test feasible. The g sums given, though incomplete, do show good agreement. For these cases it is probable that interacting levels lie so far away that the g values are relatively unperturbed. g sums have been set up for other cases, but these are probably meaningless because of the greater number of expected levels which lie nearby and which would produce perturbation.

The *raies ultimes* of thorium are usually given in the literature[1] as λλ3601.040, 3538.75, and 3290.59A. These lines all appear to arise from Th III, so the present classification does not apply to them. λ4019.137, also listed as an ultimate line, belongs to Th II and is classified in Group A as $a^4F_{1\frac{1}{2}}-y^2F^\circ_{2\frac{1}{2}}$.

Much more material on Th II is available for extension of the analysis here given, and we hope to continue the classification when opportunity permits.

We are grateful to the M.I.T.-W.P.A. Wave-Length Project for valuable data and assistance, and to the Rumford Committee of the American Academy of Arts and Sciences for a grant to assist in the purchase of pure chemicals.

Spectroscopy Conference

A SPECTROSCOPY Conference will be held at the University of Chicago on June 22 to 25, 1942. The preliminary program is as follows:

Monday, June 22, 9:30 A.M., Eckhart Hall, Room 133

Introduction to the Conference, R. S. MULLIKEN, *University of Chicago*

SPECTROSCOPIC METHODS

Discussion chairman, H. G. GALE, *University of Chicago*

1. **The Primary Standard of Wave-Length.** W. F. MEGGERS, *National Bureau of Standards.*
2. **The Measurement of Standard Wave-Lengths by the Reflection Echelon Method.** W. E. WILLIAMS, *Pasadena.*
3. **Generalized Theory of the Concave Grating.** H. G. BEUTLER, *University of Chicago.*

Monday, June 22, 2:00 P.M., Eckhart Hall, Room 133

THE SPECTRA OF COMETS

Discussion chairman, N. T. BOBROVNIKOFF, *Perkins Observatory*

1. **Molecular Bands in Cometary Spectra: Intensity Measurements.** A. MCKELLAR, *Dominion Observatory.*
2. **Molecular Bands in Cometary Spectra: Identifications.** P. SWINGS, *Yerkes Observatory.*

Monday, June 22, 8:00 P.M., Eckhart Hall, Room 133

SPECTROSCOPIC APPLICATIONS OF ATOMIC BEAMS

Discussion chairman, G. S. MONK, *University of Chicago*

K. W. MEISSNER, *Purdue University;* R. A. FISHER, *Northwestern University;* J. E. MACK, *University of Wisconsin;* W. E. WILLIAMS, *Pasadena.*

Tuesday, June 23, 9:30 A.M., Eckhart Hall, Room 133

THE EARTH'S ATMOSPHERE AND THE CONSTITUTION OF THE PLANETS

Discussion chairman, O. R. WULF, *University of Chicago*

1. **Meteors and the Earth's Upper Atmosphere.** F. L. WHIPPLE, *Harvard Observatory.*
2. **The Light of the Night Sky.** C. T. ELVEY, *McDonald Observatory.*
3. **The Geochemistry of the Atmosphere in Relation to the Constitution of the Terrestrial Planets.** R. WILDT, *Princeton University.*

Tuesday, June 23, 2:00 P.M., Eckhart Hall, Room 133

ATOMIC SPECTRA

Discussion chairman, R. A. FISHER, *Northwestern*

1. **Atomic Spectra of the Rare Earth Elements.** W. F. MEGGERS, *National Bureau of Standards.*
2. **Absorption Spectra of Alkali Metals.** J. E. MACK, *University of Wisconsin.*

Tuesday, June 23, 6:00 P.M.—Conference Dinner

Wednesday, June 24, 9:30 A.M., Auditorium, Museum of Science and Industry

TRIATOMIC SPECTRA

Discussion chairman, H. H. NIELSEN, *Ohio State University*

1. **Infra-Red Spectra of Triatomic Molecules.** E. F. BARKER, *University of Michigan.*
2. **Electronic Structures and Spectra of AO_2 Molecules.** R. S. MULLIKEN, *University of Chicago.*
3. **Emission Spectrum of the Ion CO_2^+.** S. MROZOWSKI, *University of Chicago.*

Wednesday, June 24, 2:00 P.M., Museum of Science and Industry

ELECTRONIC SPECTRA OF ORGANIC MOLECULES

Discussion chairman, K. F. HERZFELD, *Catholic University*

1. **The Interpretation of Ultraviolet Absorption Spectra in Terms of Resonance Structures.** W. H. RODEBUSH, *University of Illinois.*
2. **Ultraviolet Spectra of Substituted Benzenes.** H. SPONER, *Duke University.*
3. **Electronic Absorption of Benzene and Substituted Benzenes.** A. L. SKLAR, *Catholic University.*

Wednesday, June 24, 8:00 P.M.

SPECTRA OF DYE MOLECULES

Discussion chairman, W. G. BROWN, *Chicago*

1. **Historical Introduction.** W. G. BROWN, *University of Chicago.*
2. **Absorption and Structure-Degeneracy in Dyes.** L. G. S. BROOKER, *Eastman Kodak Company.*
3. **Energy Levels and Color of Polymethine Dyes.** A. L. SKLAR, *Catholic University.*

Thursday, June 25, 9:30 A.M.

ELECTRONIC SPECTRA OF ORGANIC MOLECULES

Discussion chairman, G. W. WHELAND, *University of Chicago*

1. **The Absorption Spectra of a Series of Dienes.** E. P. CARR AND L. W. PICKETT, *Mount Holyoke.*
2. **Theoretical Studies on Electronic Spectra.** R. S. MULLIKEN, *University of Chicago,* AND C. A. RIEKE, *Massachusetts Institute of Technology.*
3. **Calculation of the Absorption Spectrum of the Wurster Salts.** M. GOEPPERT-MAYER, *Columbia University.*

Thursday, June 25, 2:00 P.M.

COOPERATIVE SPECTRA

Discussion chairman, J. FRANCK, *University of Chicago*

1. **Influence of Environment and Aggregation upon the Absorption Spectra of Dyes.** S. E. SHEPPARD, *Eastman Kodak Company.*
2. **The Absorption and Emission of Light as a Function of Molecular Orientation.** G. N. LEWIS, *University of California.*

Thursday, June 25, 8:00 P.M.

COOPERATIVE SPECTRA

Discussion chairman, P. PRINGSHEIM, *University of Chicago*

1. **The Spectra of Some Polymerized and Associated Ions.** E. RABINOWITCH, *Massachusetts Institute of Technology.*
2. **The Spectra of Some Ions in Fields of Various Symmetry in Crystals and Solutions.** S. FREED, *University of Chicago.*

A System of Photometric Concepts

PARRY MOON
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(Received November 25, 1941)

1. INTRODUCTION

DESPITE the valuable work that has been done by the Commission Internationale de l'Eclairage, the Illuminating Engineering Society, the Optical Society of America, and other organizations in standardizing photometric definitions, the subject remains in an unsatisfactory state. The physicist who deals with radiant energy seems ordinarily to make up his nomenclature as he goes along, with slight reference to what has been done before. The astrophysicist finds little that he can use in the standardized concepts of the illuminating engineering societies and is forced to depend on his own resources. Likewise, the meteorologist finds that the subject that interests him—the passage of light through absorbing and scattering media—is completely ignored in the standard lists of concepts. The lighting technician has been responsible for most of the standardization but he cares ordinarily about only a small part of the complete subject.

The present photometric concepts were developed to meet the simple needs of the illuminating engineer of the past. The tacit assumption was made that the media were perfectly transparent and non-dissipative. Surfaces were generally assumed to be perfectly diffusing. Sources were either "point sources" or surface sources with uniform characteristics. Today the engineering applications of light are growing at an unprecedented rate and the antiquated theoretical basis of lighting calculations is beginning to cause trouble. There is no reason why a comprehensive system of concepts cannot be developed so that the broad subject of photometrics can be treated as an entity. The needs of the physicist, the astrophysicist, the meteorologist, the illuminating engineer, the colorimetrist, and the photographer will be satisfied by such a set of concepts and much of the complexity and confusion, so evident in the literature, will be eliminated.

It is the purpose of this paper to present a comprehensive system of concepts, names, and units associated with the geometric relations that occur in radiometry and photometry. The proposed set of concepts is the result of many revisions extending over the past twelve years. Any merits that it possesses are ascribable to the reactions of illumination classes which were used as guinea pigs during the various stages of its development, and particularly to the experts, too numerous to mention, who have helped with detailed criticisms. To all such, my sincere thanks.

2. PHOTOMETRICS

Photometrics or theoretical photometry may be divided into two parts: *physical photometrics* and *geometrical photometrics*, corresponding roughly to physical optics and geometrical optics. Physical photometrics deals with the calculation of radiant energy and light where variations with wave-length are important, while geometrical photometrics deals with the geometric relationships that are common to radiations of all wave-lengths. Only the latter subject will be considered in the present paper.

Let X_λ be radiant power in watts in the wave-length band $(\lambda, \lambda+d\lambda)$. Starting with this basic idea, geometrical photometrics considers such related concepts as radiant power per unit area, radiant power per unit solid angle, etc., all for the same band of wave-lengths. As an extension of the subject, consider an exactly analogous set of concepts with X_λ replaced by X, where

$$X=\int_0^\infty X_\lambda d\lambda. \tag{1}$$

Such a set of concepts follows exactly the same geometric relations as the previous set and can be used whenever the media considered in the calculations are non-selective.

But if the media are non-selective, one may equally well use an arbitrary weighting function $w(\lambda)$ in Eq. (1), giving a new set of quantities:

$$X'=\int_0^\infty w(\lambda)X_\lambda d\lambda. \tag{2}$$

The weighting function may be the standard *lamprosity*[1] function for the human eye, or it may represent the spectral response curve of photoelectric, photographic, erythemal, fluorescent, and other effects. The radiant energy can be evaluated with respect to various receptors, and a set of concepts can be built up in each case. The important fact is that for any given system of concepts (radiometric, photometric, erthemal, etc.) the same purely geometric relations among the various quantities hold. *These geometric relations can be studied advantageously as a separate discipline known as geometrical photometrics.*

The parallel sets of concepts have usually been treated separately, each concept having its own name, symbol, and units. This has resulted in such complexity that many investigators have felt that more than two sets (radiometric and photometric) were impracticable. If, however, the same name and symbol are used for the corresponding concept in all systems, the logical treatment of erythemal and other systems puts no burden on the memory or on the typesetter. *It is proposed, therefore, that a single set of symbols and names be used to indicate the relations of geometrical photometrics* and that these same symbols and names be used for radiometric, photometric, and any other systems that may be desirable. Often an extended mathematical argument is carried on completely in one of these systems, in which case no ambiguity will occur. If several systems are considered in a single investigation, subscripts can be used, as F_r for radiant power (radiant flux), F_l for luminous flux, F_e for erythemal flux, etc. When subscripts are also used for other purposes, the proposed arrangement will sometimes lead to double subscripts. There should be no serious objection to double subscripts, however, and their use is probably better than the use of single superscripts with single subscripts.

The treatment of geometrical photometrics given in the following pages divides itself into four parts: I. Concepts; II. Names of concepts; III. Units of their names; IV. Final definitions and examples of their use. The first subject deals with the concepts that have been in use and the concepts that are recommended. Having decided on the concepts that should be used, one is in a position to choose names for these concepts, which is an entirely separate consideration. The units are chosen next. Finally, a brief résumé of the field of geometrical photometrics is given, showing that the chosen concepts are sufficient to treat the entire subject.

[1] Parry Moon, "Basic principles in illumination calculations," J. Opt. Soc. Am. **29**, 108 (1939).

CONCEPTS

3. How Many Concepts?

The development of a branch of science starts with one or more fundamental ideas. Various relations are deduced; and in writing down the equations, one finds certain combinations of symbols occurring frequently. In many cases, particularly when these combinations have definite physical significance, they are represented by new symbols and are considered as new concepts. Advantages of introducing new concepts are the simplification of the equations and the increased mental grasp of the subject. Routine engineering work on a small section of the general subject usually produces various short cuts, including further concepts and symbols. Such procedure often leads to inconsistencies with the main body of nomenclature and tends to increase the number of concepts beyond the optimum.

The question of how many concepts should be adopted is, and always will be, a matter of personal opinion. When a combination of quantities occurs very infrequently, however, it should not be set up as a separate concept, for the advantages to be gained by such a step may be more than compensated by the disadvantage of learning and remembering the definition. For instance, some of the concepts of mechanics such as *action* hardly need be dignified by separate names and symbols. In electric circuit theory, it is a moot question whether the concepts of *admittance*, *susceptance*, and *conductance* are not more trouble than they are worth. All the equations can be written without these concepts, and it is questionable whether the additional burden on the memory is balanced by the slight simplification of some of the equations.

Photometrics is burdened by an extraordinary large number of unnecessary concepts. One of them, which is so obviously unnecessary that it has not been included in the following tables, is

TABLE I. Principal concepts.

Concept	Dimensions	C.I.E. (reference 11), 1938	I.E.S. (reference 2), 1941.	Ives (reference 4), 1917.	Walsh,[a] 1926.	Fabry,[b] 1927.	Blondel (reference 5), 1928.	L. & P.,[c] 1928.	Higbie,[d] 1934.	Forsythe,[e] 1937.	Jones (reference 6), 1937.	Gershun (reference 7), 1936	Boldyreff,[f] 1938.	Moon (reference 8), 1936.	Moon, 1942.
Luminous flux	F	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Flux to a surface	F			●											
Flux from a surface	F			●											
Flux density	FL_t^{-2}	●													●
Flux den. to a surface ("illumination")	FL_t^{-2}	●	●	●	●	●	●	●	●	●	●	●	●	●	
Flux den. from a surface ("luminosity")	FL_t^{-2}	●		●		●	●				●	●	●	●	
Flux-density vector	FL_t^{-2}											●	●		
"Spacial illumination"	FL_t^{-2}											●	●	●	
Flux·time ("quantity")	FT	●	●	●	●	●	●	●	●		●	●	●	●	●
Flux·time to a surface	FT														
Flux·time from a surface	FT														
Flux·time, per unit volume	$FTL_t^{-3}L_r^{-1}$											●	●		
Flux density·time	$FL_t^{-2}T$														●
Flux density to a surface	$FL_t^{-2}T$	●				●	●								
Flux density from a surface	$FL_t^{-2}T$														
Flux per unit solid angle ("intensity")	$FL_t^{-2}L_r^2$	●	●	●	●	●	●	●	●	●	●	●	●	●	
Flux per unit solid angle·time	$FL_t^{-2}L_r^2T$														
Flux per unit solid angle, per unit of projected area ("brightness")	$FL_t^{-4}L_r^2$	●	●	●	●	●	●	●	●	●	●	●	●		
Flux per unit area of receiving surface, per unit solid angle	$FL_t^{-4}L_r^2$											●			●
Flux per unit solid angle, per unit volume of source	$FL_t^{-4}L_r$														
Flux per unit area of receiving surface, per unit solid angle, per unit distance	$FL_t^{-4}L_r$														●
Number of concepts		8	5	8	5	7	7	5	5	4	6	10	9	6	6

[a] J. W. T. Walsh, *Photometry* (London, 1926).
[b] C. Fabry, *Introduction Générale à la Photométrie* (Paris, 1927).
[c] Lax and Pirani, *Lichttechnik* (in Geiger and Scheel, *Handbuch der Physik*) (Springer, 1928), Vol. 19, p. 331.
[d] H. H. Higbie, *Lighting Calculations* (Wiley, 1934).
[e] W. E. Forsythe, *Measurement of Radiant Energy* (McGraw-Hill, 1937).
[f] N. G. Boldyreff, *Theoretical Photometry* (in Russian) (Leningrad, 1938).

daylight factor. It is merely the ratio of two values of flux density, is used relatively infrequently, and is more easily understood when written as a ratio than when hidden under the esoteric cloak of a separate symbol.

4. The Usual Concepts

The usual photometric concepts are listed in Table I. Only the most important concepts of geometrical photometrics are considered. On the other hand, the list includes concepts which have not been used in the past but which are logically justified. That is, if *flux density to a surface* and *flux density from a surface* are both desirable, should we not have also as distinct concepts *flux to a surface* and *flux from a surface?* Equally justifiable are *quantity to a surface* and *quantity from a surface.*

It is interesting to note the similarity of concepts used by the various writers. In the United States, the concepts recommended by the I.E.S. are generally used, though H. E. Ives differs from others in advocating *three* luminous fluxes. In France two additional concepts (Table I) seem to be practically universal: *flux density from a surface* ("radiance") and *flux density to a surface·time* ("exposure"). The C.I.E. concepts are the same as those of Blondel and Fabry except for an additional definition of flux density devoid of direction. The Russians are more original in their treatment but employ an unnecessarily large number of concepts.

One of the peculiarities of the usual photometric nomenclature is the use of "to and from concepts." Nowhere else in physics does there seem to be this desire to introduce separate and distinct concepts, names, and units depending on *direction*. But in photometrics we have the "to-concepts" of *illumination* (luminous flux *to* the surface, per unit area) and *exposure* (illu-

mination·time), and the "from-concepts" of *intensity* (flux from the source, per unit solid angle), *brightness* (intensity per unit of projected area of source), and *flux from the source, per unit area* (called variously *radiance, specific luminous emittance,* and *luminosity*).

Each of these concepts has, in general, its own units. Thus the unit of illumination commonly employed in the United States is called the "foot-candle," but this unit must not be used to designate the luminosity, though both are actually in *lumens per square foot.*

One cannot deny that "to and from concepts" are often convenient in illuminating engineering, since they eliminate the necessity of writing "to," and "from," or similar words. A great number of other shorthand notations can be introduced and are convenient in a similar way, but they carry with them the trouble of learning and remembering an increased number of specialized ideas. Exactly where is the best compromise? One may well doubt if the slight additional convenience of the "to and from concepts" balances the additional complexity which they introduce.

Somewhat analogous is the situation that arises in considering the input and output of machines. The efficiency of a transformer, for instance, may be written

$$\eta = P_o/P_i.$$

It is usual to employ the same symbol for both output and input, the two being distinguished by means of subscripts. No one has found it necessary to consider P_o and P_i as essentially different quantities, each with its own dimensions and its own units. Similarly, there is no necessity of considering luminous flux from a surface and luminous flux to a surface as intrinsically different things. The same symbol can be used for both and the subscripts o and i can be employed when necessary.

5. Dimensions

The use of *dimensions* is practically unknown in photometric theory. The usual L, M, and T lead to the conclusion that the lumen and the candle are identical, as are illumination, brightness, and luminosity. Such conclusions are anything but welcome to photometrists and probably explain the absence of any mention of dimensions in illuminating engineering texts. One must rid himself of the superstitious awe that seems to envelop the subject of dimensions and must realize that any dimensions can be introduced that are convenient for the problem in hand. In particular, it is necessary to distinguish between distances measured *radially* (along a light ray) and *tangentially*. For this purpose, the two dimensions L_r and L_t will be introduced. Other dimensions needed are F for luminous flux and T for time. Then the dimensions of a plane angle are $L_t L_r^{-1}$. For a solid angle,

$$L_t^2 L_r^{-2};$$

and for luminous intensity (flux per unit solid angle),

$$F L_t^{-2} L_r^2,$$

which no longer has the dimensions of flux.

Similarly, the dimensions of illumination are

$$F L_t^{-2}$$

and of brightness,

$$F L_t^{-4} L_r^2.$$

These dimensions are included in Table I.

6. Recommended Concepts

The requirements for a set of concepts may be written as (a) Generality, (b) Simplicity, (c) Conformity with the rest of physics. The fundamental definitions should be such that the whole subject of geometrical photometrics becomes merely a logical unfolding of the applications of fundamental principles. The usual system of concepts[2] is too indefinite and too loosely knit to allow any such unfolding. It is puzzling to know which of the concepts are applicable in absorbing and diffusing media. No provisions are made for the treatment of volume sources. The fact that pages are devoted to the definition of the single concept of brightness indicates a lack of simplicity. The established definitions are still based essentially on the work of Lambert,[3] which was excellent in 1760 but which has little relation to modern physics.

Revisions in photometric nomenclature have

[2] "Illuminating engineering nomenclature and photometric standards," Illum. Eng. **36**, 815 (1941).

[3] J. H. Lambert, *Photometria Sive de Mensura et Gradibus Luminis, Colorum et Umbrae* (1760).

been proposed by H. E. Ives,[4] André Blondel,[5] L. A. Jones,[6] A. Gershun,[7] and many others. Most of these suggestions have dealt with details and have left the main framework of photometrics relatively unchanged. An attempt to simplify radically the teaching of the subject disclosed the fact that all the ordinary calculations could be made with the help of only two principal concepts,[8] thus eliminating a number of involved and difficult ideas that are usually considered necessary. The selected ideas were *flux* and *flux density*. The requirement (b) of simplicity is evidently satisfied, and the concepts are closely related to ideas found in electricity, magnetism, and other branches of physics, in accordance with (c).

This simplified set of concepts is satisfactory if the surfaces are perfectly diffusing (or perfectly specular) and if the media between them are perfectly transparent. It is likely, however, that much attention will be paid in the future to imperfectly diffusing surfaces and to the calculation of the glare to be expected from such surfaces. These questions require a concept like brightness. Volume sources and scattering media are likewise outside the scope of the simplified set, which therefore definitely fails in requirement (a).

The last column of Table I indicates an attempt to get the simplest possible set of concepts consistent with the satisfactory handling of problems in the entire field of geometrical photometrics. *Only six concepts are used and only three of these are needed in most applications.* The concepts are:

1. Flux
2. Flux density
3. Flux density per unit solid angle
4. Flux density per unit solid angle per unit thickness of source
5. Flux·time
6. Flux density·time.

The first three were advocated in a paper presented in 1938. Further consideration indicated that the fourth concept was desirable in the treatment of diffusing media and volume sources.

The basic concept is taken as a *flux*, in accordance with most modern work on photometrics. The older idea was to use either candlepower or quantity as the basic concept, the former being introduced merely as a matter of practical technique (an actual candle being used as standard) and the latter because of its relation to energy. The nineteenth century physicist apparently looked upon some concepts as holding kingship by divine right. Of these the supreme being was perhaps *energy*. The modern view is that since all concepts are man-made inventions, one of them is inherently no more fundamental than another, and which should be considered first depends entirely on convenience. On this basis, *power* can be used advantageously as a starting point rather than energy, and *flux* can be used rather than *flux·time*.

Table I shows that the recommended system contains no "to and from concepts." "Illumination" and "luminosity" are replaced by the single concept of *flux density*. The word "illumination" can now be reserved for the *process* or for other qualitative ideas, while the quantitative aspect is now called "flux density to the surface." The third recommended concept is a generalized "brightness." The fourth is the increment in this generalized "brightness" per unit thickness of volume source. It is interesting to note that all of the many investigators[9] of volume sources and scattering media use some sort of equivalent concept but none of the standard lists of photometric definitions mentions such a quantity.

The concept *flux·time* does not enter very frequently in photometrics because the eye and most other receptors ordinarily respond to flux, not total quantity. But in the consideration of isolated flashes (as from a lighthouse, for instance) the equations will naturally contain such quantities as flux·time. Logically one might

[4] H. E. Ives, "Units and nomenclature of radiation and illumination," Astrophys. J. **45**, 39 (1917).

[5] A. Blondel, "Sur les grandeurs et unités photométriques," Rev. Gen. d'Elec. **23**, 1099 (1928).

[6] L. A. Jones, "Colorimetry: preliminary draft of a report on nomenclature and definitions," J. Opt. Soc. Am. **27**, 207 (1937).

[7] A. Gershun, "The light field" (in Russian), (Moscow, 1936). English translation by Moon and Timoshenko, J. Math. Phys. **18**, 51 (1939); M.I.T. E.E. Dept. Contr. No. 164 (1939).

[8] Parry Moon, *Scientific Basis of Illuminating Engineering* (McGraw-Hill, 1936).

[9] See, for example, K. Swarzschild, *Über Diffusion und Absorption in der Sonnenatmosphäre* (König. Preuss. Akad. d. Wiss., 1914), p. 1183. A. Unsöld, *Physik der Sternatmosphären* (Springer, 1938). E. Hopf, *Mathematical Problems of Radiative Equilibrium* (Cambridge University Press, 1934).

expect that each of the concepts containing flux would have an analog containing flux·time. Many of these concepts have never found their way into any text or standard table of photometrics, however, and it is likely that two such quantities will satisfy all ordinary needs. The fifth and sixth of the foregoing concepts are introduced to satisfy the demand for quantities of this type.

It will be noted that the familiar quantity "intensity" or "candle-power" is absent in the new set. It was a potent concept when light sources were of small dimensions and when all lighting calculations could be made with the inverse-square law. As the art advanced, however, the inverse-square law became less and less useful, until today its sole function seems to be to confuse those who are not aware of its limitations. For example, the 40-watt fluorescent lamp is so large that the inverse-square relation is not applicable unless the ceiling height is 10 meters or more, and thus candlepower-distribution curves for such lamps are of little value. A flux-density distribution curve on a specified surface or at a specified distance gives all the information that the old cp-distribution curve gave and is a more precise specification. The concept of candlepower is obsolete.

Definitions of the recommended quantities will be given later in connection with their recommended units. Also, the final section of the paper will give an outline of photometrics, using only the foregoing set of six concepts and showing that they allow the entire field to be covered without undue circumlocutions.

NAMES OF CONCEPTS

7. Requirements of a Name

In the preceding paragraphs, six concepts have been recommended but names have not been assigned to them. It is advantageous to proceed in this way, first deciding upon the concepts themselves, and then considering their names as a separate investigation. As discussed in another paper,[10] the name of a scientific concept should have the following qualifications: (a) Unambiguity, (b) Internationality, (c) Simplicity, (d) Euphony.

[10] Parry Moon, "The names of physical concepts." (To be published in the near future.)

That the names of concepts should be reasonably simple, euphonious, and easily remembered needs no further comment. There is also an advantage in having words that are international. Many scientific terms are already in this category. For instance, *energy* is an international word[11] (E. *energy*, F. *energie*, G. *Energie*, I. *energia*, S. *energia*, Esperanto, *energio*) but power is not (E. *power*, F. *puissance*, G. *Leistung*, I. *potenza*, S. *potencia*, Es. *potenco*). Present photometric names are not international (for instance, E. *brightness*, F. *brillance*, G. *Leuchtdichte*, I. *splendore luminoso*, S. *brillo*, Es. *helodenso*). Other names are given in Table II.

By far the most important requirement is that a scientific word be unambiguous, which requires essentially that a new word be coined for each new scientific concept. In the past it has been customary in naming concepts to use words already in the language. This process results in two meanings for the same word: a precise scientific meaning, and a vague, popular meaning. There is no necessary connection between the two. For an ideally logical people, this state of affairs would cause no difficulty; but for actual scientists and engineers it results in an extraordinary number of errors.[12] No one objects to the coining of a new name for each newly invented machine: How much more important is the coining of a new name for a newly invented concept!

8. Recommended Names

The proposed names, for the concepts that were recommended in the previous section, are given in Table III. The basic words are Greek as outlined in another paper.[10] The endings conform

[11] Commission Internationale de l'Eclairage, Vocabulaire, National Phys. Lab., Teddington, England, 1938. International electrotechnical vocabulary, International Electrotech. Comm. (London, 1938).

[12] The fact is generally recognized, though not ordinarily by engineers. For instance, J. S. Mill says, "The tendency has always been strong to believe that whatever receives a name must be an entity or being, having an independent existence of its own: And if no real entity answering to the name could be found, men did not for that reason suppose that none existed, but imagined that it was something particularly abstruse and mysterious, too high to be an object of sense." "When familiar words are stretched and put to new uses, confusion is bound to result. The meaning we attach to words is based on habits which arbitrary resolutions cannot readily change, and we invariably drag the old meaning into the new context."—M. R. Cohen, *Reason and Nature* (New York, 1931), p. 454.

TABLE II. Usual names of concepts.

Symbol	English	French	German	Italian	Spanish	Esperanto
F	luminous flux	flux lumineux	Lichtstrom	flusso luminoso	flujo luminoso	lumoflukso
—	luminous flux density	densité du flux lumineux	Flächen-licht-stromdichte	densità superficiale del flusso luminoso	densidad del flujo luminoso	—
E	illumination	éclairement	Beleuchtungs-stärke	illuminamento	iluminación	lumigo
I	luminous intensity	intensité lumineuse	Lichtstärke	intensità luminosa	intensidad luminosa	lumintenso
B	brightness	brillance	Leuchtdichte	splendore luminoso	brillo	helodenso
R, L	radiance, luminosity	radiance	spezifische Lichtaus-strahlung	luminosità	radiancia	radieco
—	exposure	excitation	Belichtung	eccitazione	—	—
Q	quantity of light	quantité de lumière	Lichtmenge	quantità di luce	cantidad de luz	lumokvanto

with the following arbitrary scheme:

-ent = per unit distance (as in "gradient")
-age = per unit area (as in x-ray "dosage")
-um = per unit volume.

The word *phos* (Gk. φῶς = light) replaces the usual expression "quantity of light." The other two basic words were selected as being the shortest and most euphonious of available Greek words associated with light. They are *helios* (ἥλιος = the sun) replacing the word "brightness" and *pharos* (φάρος = a lighthouse) replacing "flux." The old word "flux" implies the existence of a more fundamental quantity that is "flowing," and it is thus an inconsistent term to use for the basic quantity in a set of definitions.

In introducing a new set of words, one is also privileged to fix the pronunciation. The following simple rules will apply: the stress is always on the penultimate syllable (except in hel′ i os), and the vowels are to be pronounced as in most European languages: That is, *a* as in *father*, *e* like the *a* in *fate*, *i* as in *machine*, and *o* as in *ohm*.

For the generalized brightness, *H*, the name *selance* (σέλας = brightness) was coined[1] in 1938. A subsequent examination of the names of all physical concepts indicated that the ending *-ance* was not advisable in the name for this quantity. Very little in the way of a correlative principle can be found among the names of physical concepts; the only examples seem to be those with the endings *-ity*, and *-ance*. In general, the ending *-ity* indicates a *property of a material*, as density, permeability, susceptibility, reluctivity, viscosity, resistivity, conductivity. The ending *-ance* refers to a *passive characteristic of a device*. Thus, one speaks of the electrical *resistance* of a definite coil of wire or the *reluctance* of a given magnetic circuit. Other international words of this kind are inductance, capacitance, permeance, reactance, impedance, admittance, conductance, susceptance. There are exceptions (such as *velocity*, *intensity*) but the principle seems to be well enough established so that it should be observed in the coining of new names.[13]

The name "brightness" should not be used for *H*. The name has already caused much confusion, and its use for still another concept would be most reprehensible. Not only has it been given a number of photometric meanings but it is in frequent use in its popular sense and has still different specialized meanings to the artist, the colorimetrist, and the psychologist. If the term is abandoned completely in photometrics, "brightness" can be employed more freely in its qualitative sense, with greatly reduced danger of misunderstanding.

The names are proposed as *international words*, which can be incorporated without change into all languages. Examination of the present scientific names shows that whenever a concept has been introduced with a name taken directly from Greek or Latin, this name has ordinarily been accepted by all language groups. When, however, an English, French, or German word is originally

[13] The other name advocated in 1938—*lamprosity*, for the C.I.E. standard visibility curve—is still considered as appropriate, since it is closely related to a property of the photochemical substances in the retina.

used, each language group uses an equivalent word in its own language instead of the original. This lack of internationality is a frequent source of misunderstanding.

The words of Table III will appear very strange and repulsive to most people. They are not difficult words, however, and it will be found that a beginner who has never heard of photometrics before will assimilate the names and definitions with surprising nonchalance. The principal advantage of the new words is the elimination of ambiguity, though they also satisfy the other requirements enunciated at the beginning of this section.

TABLE III. Proposed international names of concepts.

Symbol	Dimensions	Name
F	F	pharos (or flux)
D	FL_i^{-2}	pharosage (or flux density)
H	$FL_i^{-4}L_r^2$	helios
G	$FL_i^{-4}L_r$	heliosent
Q	FT	phos
W	FTL_i^{-2}	phosage

[14] Note that the *diopter* is a metric unit.

UNITS AND THEIR NAMES

9. The Customary Units

The dimensions of the photometric concepts (Table I) indicate that photometric units will depend on the units chosen for flux, length, and time. Luminous flux is universally expressed in *lumens*, while time is usually expressed in *seconds*. The unit of length, however, may cause disagreement. Though the width of cinema film is always given in mm, ball bearings and many other parts are made on the metric system, the focal length of lenses is often given in metric units,[14] wavelengths (both radio and light) are metric, nevertheless the American illuminating engineer still chooses to be provincial in his unit of length.

The practicing technician in this country uses three photometric concepts: flux, intensity, and illumination. Two of these are standardized internationally, leaving only the unit of illumination in doubt. It is just as easy to read a photoelectric illumination meter calibrated in lumens per square meter as to read one calibrated in lumens per square foot, and it is indeed unfortunate that the United States public is now being light-educated in the use of the antiquated British system instead of the metric system.

TABLE IV. Names of units recognized by the C.I.E.

Symbol	Name of Concept	Name of Unit c.g.s.	Name of Unit m.k.s.
F	flux	lumen	lumen
E	illumination	phot	lux
L	radiance	—	—
I	intensity	new candle*	new candle*
B	brightness	stilb	—
Q	quantity	lumen-sec	lumen-sec
—	exposure	phot-sec	lux-sec

* Resolution of Comité International des Poids et Mesures (Paris, 1937). See also, International Lighting Vocabulary (C.I.E.) (Teddington, England, 1938).

The names adopted by the C.I.E. for units in both c.g.s. and m.k.s. systems are listed in Table IV. The *lumen* was proposed by Blondel in 1894 and is now universally accepted. The names, *phot* and *stilb* were likewise coined by Blondel (1921) and are in general use on the Continent. All the names of units in Table IV are international except *candle*, which remains completely different (but equally anachronistic) in all languages[15] (E. *candle*, F. *bougie*, G. *Kerze*, I. *candela*, S. *bujia*, Es. *kandelo*). Luckily, it will not be necessary to worry about this name, since the concept is not included in the recommended set.

10. Recommended Units

The concepts, symbols, and names of concepts can be applied equally well to all systems. When necessary to prevent confusion, subscripts are used on the symbols and qualifying adjectives are employed to specify whether the quantity is in the radiometric, photometric, erythemal, or bactericidal set.

When *units* are considered, however, this generality must be abandoned. Each set of concepts should preferably have its own units. Only radiometric and photometric units will be considered here, though units for other fields are easily developed on similar lines.

The units *lumen*, *lumen-sec*, *watt*, and *watt-sec* (joule) are thoroughly established. The same quantities per square meter should likewise cause

[15] Regarding the difference in English, French, and German, Blondel says (Rev. Gen. d'Elec. **23**, 1102 (1928)), "Malgré les efforts que nous avons faits en 1896 pour faire adopter un vocable unique tiré du grec, l'unité d'intensité a conservé son manteau d'arlequin en trois couleurs."

TABLE V. Recommended radiometric and photometric units.

Radiometric				Photometric			
Symbol	Dimensions	Name of Concept	Unit	Symbol	Dimensions	Name of Concept	Unit
F_r	P	radiant power, or pharos (radiant)	watt	F	F	pharos (or luminous flux)	lumen
D_r	PL_t^{-2}	pharosage (radiant)	watt m^{-2}	D	FL_t^{-2}	pharosage (or flux density)	lumen m^{-2}
H_r	$PL_t^{-4}L_r^2$	helios (radiant)	herschel	H	$FL_t^{-4}L_r^2$	helios	blondel
G_r	$PL_t^{-4}L_r$	heliosent (radiant)	herschel m^{-1}	G	$FL_t^{-4}L_r$	heliosent	blondel m^{-1}
Q_r	PT	radiant energy, or phos (radiant)	watt-sec	Q	FT	phos	lumen-sec
W_r	PTL_t^{-2}	phosage (radiant)	watt-sec m^{-2}	W	FTL_t^{-2}	phosage	lumen-sec m^{-2}

little question, though some of the names (lumen-seconds per square meter) are cumbersome.[16] Remaining are only the questions of units for H and G.

The most fundamental relation in geometrical photometrics deals with the flux between two small apertures dS_1 and dS_2. A line of length r joins the centers of these two apertures, and the angles between this ray and the normals to dS_1 and dS_2 are θ_1 and θ_2, respectively. The flux from dS_1 to dS_2 is directly proportional to the areas and to the cosine of the angles, so

$$d^2F_{12}=K(dS_1dS_2\cos\theta_1\cos\theta_2/r^2) \qquad (3)$$

or

$$dD_2=K\cos\theta_2 d\omega_2, \qquad (3a)$$

where $d\omega_2$ is the solid angle, with apex at dS_2, subtended by dS_1. The constant of proportionality K represents a new concept which turns out to be directly proportional to the helios, or

$$K=H/k, \qquad (4)$$

where k may have any value. Only two values, 1 and π, will be considered. The first corresponds in the older notation to "brightness in candles per unit area," while the latter is similar to "brightness in lamberts." The question of which will be used is similar to a question of electrostatics—shall a 4π be introduced into Coulomb's law—a question that is still the cause of controversy among electrical engineers.

The use of π in the definition of helios results in such an important simplification in practical calculations that its advantages are believed to greatly outweigh its disadvantages. In lighting calculations, one of the most frequent steps is the change from D_i, the incident flux density, to H. With perfectly diffusing surfaces and with $k=\pi$,

$$H=\rho D_i, \qquad (5)$$

where ρ is the reflection factor of the surface. Also, with very large surface sources of uniform H (uniform sky, for instance), the flux density at any point is

$$D=H.$$

If H is defined with $k=1$, both of the foregoing equations will contain π. A serious attempt was made to use this "unrationalized" system but the annoyance caused by continually putting in and taking out π's proved to be so great that it was abandoned. The only valid objection to the rationalized system appears to be the danger that the uninitiated will confuse H with the completely different concept D. With a perfectly diffusing surface having unit reflection factor, H is *numerically equal* to D; but that of course does not make the two concepts equal any more than the balance of one kg of salt and one kg of sugar on the scales allows us to write the equation, sugar = salt.

Helios will be defined, therefore, by the equation,

$$H=\pi(dD/d\omega)\cos\psi. \qquad (6)$$

The unit is π times the lumens per square meter per steradian. Such a name is impossibly cumbersome, so a new name is proposed, the *blondel*, after André Blondel who did pioneer work in photometric nomenclature. The corresponding name in the radiometric system is the *herschel*.

It will be noted that the units of Table V belong to the m.k.s. system rather than to the c.g.s. system. There are two reasons for this choice. In the first place, the photometric and

[16] The word *lux* cannot be used as the unit of flux density because it has been accepted internationally for the "to-concept" of *illumination*.

radiometric magnitudes most frequently used are expressed in convenient numbers with the meter as unit of length. For instance, an illumination of *10.0 "foot-candles"* becomes in the new system *107.6 lumen* m^{-2}, which is somewhat more convenient than the equivalent 0.01076 lumen cm^{-2}. A diffusing globe with a brightness of *2.5 candles in.*$^{-2}$ is now said to have a helios of *3870 blondels*. Direct sunlight at the earth's surface produces a maximum radiant flux density of approximately *1200 watt* m^{-2} (0.12 watt cm^{-2}). Other radiant flux densities met in practice are generally less than this value and are also conveniently expressed in the m.k.s. system. A set of conversion factors is given in Table VI. The second reason is that the m.k.s. system has been adopted by the International Electrotechnical Commission (Scheveningen-Bruxelles, June 1935) and is now being employed in much of the new work in electrical engineering.

For the units there is a tendency to use impersonal names in the c.g.s. system and personal names in the m.k.s. system.[17] Thus it seems advisable to employ personal names, as has been done for the new units in Table V, even though previous names of photometric units (Table IV) have usually been impersonal.

THE PROPOSED SYSTEM

11. Final Definitions

The six recommended concepts are

(1) *Pharos* (flux), F. Basic concept of geometrical photometrics. Therefore not defined in this subject.

(2) *Pharosage* (flux density), D, is the pharos per unit area, or

$$D=dF/dS. \tag{7}$$

Included in this concept are several subdivisions, some of which are usually considered as separate concepts:

(a) D_i, the incident flux density, usually called the *illumination*.

(b) D_o, the flux density from the surface, formerly called *luminosity*.

(c) D_m, the average flux density over a given surface.

(d) D_s, the *space-pharosage*, defined as

$$D_s=\frac{1}{\pi}\int_\omega H d\omega. \tag{8}$$

This idea was introduced by Arndt with the name "Raumbeleuchtung." It was strongly recommended for use in interior lighting by Gershun, though its principal application appears to be in calculations dealing with turbid media.

D, D_i, and D_o are scalar functions of five independent variables, three of which specify the position of a point P in the light field and two of which give the angular position of the surface normal. An alternate representation is as a vector function $\mathbf{D}$ of three independent variables.[1] D_s is a scalar function of three independent variables. It has the dimensions FL_l^{-2} and is obtained as a summation of helios over all angles.

(3) *Helios H* at a given point on a given ray is defined as

$$H=\pi(dD/d\omega)\cos\psi, \tag{6}$$

where D is measured at point P with radiant energy coming through the solid angle $d\omega$ with apex P. The angle ψ is the angle of incidence of the ray that forms the axis of $d\omega$.

TABLE VI. Conversion factors.

Present units		Proposed units
"Illumination"		*Flux Density*
1 lumen per square foot	= 10.764	lumens per square meter
1 foot-candle	= 10.764	lumens per square meter
1 meter-candle	= 1	lumen per square meter
1 lux	= 1	lumen per square meter
1 phot	= 10^4	lumens per square meter
1 milliphot	= 10	lumens per square meter
"Brightness"		*Helios*
1 lambert	= 10^4	blondels
1 millilambert	= 10	blondels
1 foot-lambert	= 10.764	blondels
1 stilb	= $\pi\times10^4$	blondels
1 apostilb (in international units)	= 1	blondel
1 candle per square inch	= 4869	blondels
1 candle per square foot	= 33.82	blondels
1 candle per square millimeter	= $\pi\times10^9$	blondels
1 candle per square cm	= $\pi\times10^4$	blondels
1 candle per square meter	= π	blondels
1 equivalent foot-candle	= 10.764	blondels
1 equivalent meter-candle	= 1	blondel

[17] A. E. Kennelly, "The adoption of the Giorgi m.k.s. absolute system of practical units," Trans. I.E.S. **31**, 685 (1936).

(4) The *heliosent* (G) at a given point P and on a given ray is equal to the helios per unit thickness (along the ray) of a volume source, or

$$G = dH/dr. \tag{9}$$

Inasmuch as the foregoing definitions will appear very strange, it seems advisable to give some additional explanation. The **D** vector may be imagined to be measured as follows. A barrier-layer photoelectric cell is placed at the point P and is gradually rotated until a maximum current is obtained. An arrow pointing out the back of the cell then indicates the direction of the **D** vector, while the reading of a microammeter (calibrated in lumens/m² incident on the cell), gives the magnitude of the vector.

The *helios* can also be measured by a barrier-layer cell placed at the point P. In this case, however, the cell is shielded from all light except that coming through a small solid angle whose axis lies in the given direction (along the given ray). If the shield is so constructed that the axis of the lightcone is perpendicular to the cell surface,

$$H = \pi \lim_{\omega \to 0} \frac{D}{\omega}. \tag{6a}$$

The flux density at P is obtained as the angle is decreased. The limiting value of the ratio $\pi D/\omega$, as ω becomes very small, is defined as the helios.

Evidently, helios is a generalization of the ordinary concept of brightness. Brightness is usually considered as an attribute of a definite luminous surface, while helios expresses a condition *at the receiving point* P, not at the source. The concept of helios applies, no matter what kind of medium (smoke, fog, etc.) lies between the source and P. With an absorbing or diffusing medium, the helios varies along the ray. For the special case of a non-absorbing and non-scattering medium, H is the same at all points along a given ray; and in this special case it reduces to the ordinary concept of brightness.

The *heliosent* is needed only for volume sources. In the interior of a gaseous-conduction lamp, for example, each layer of gas adds something to the magnitude of the helios, as one proceeds through the lamp along a given ray. The increment in helios produced per increment in distance along the ray is called the heliosent.

It should be noted that both H and G are functions of five independent variables, not three. To say "the helios at P is 7.5 blondels" is meaningless unless the direction is also specified. H and G require three space coordinates to fix the point P and two angles to fix the direction of the ray.

(5) *Phos* Q is equal to *flux·time.*

(6) *Phosage* W is equal to *flux density·time.*

12. Flux Between Apertures

A confusing aspect of the usual treatment of photometrics is that a different method seems to be employed for each type of calculation. Sometimes the inverse-square relation is used while at other times the convergent lightcone or the divergent lightcone is used. There is a real advantage in always using the *convergent lightcone* with vertex at the receiving point P. It need hardly be pointed out that this cone has absolutely no physical significance. Light does not travel down the cone and the idea is introduced merely for convenience.

The *fundamental relation of geometrical photometrics*, as pointed out in Section 10, is

$$d^2F_{12} = (H_2/\pi)(dS_1 dS_2 \cos\theta_1 \cos\theta_2/r^2), \quad \text{(lumen)} \tag{3b}$$

where d^2F_{12} = flux from aperture 1 to aperture 2
dS = area of aperture
θ = angle between aperture normal and ray from 1 to 2
r = distance between centers of dS_1 and dS_2
H_2 = helios measured at 2 in direction of 1.

The symmetry of Eq. (3b) proves that if radiant power is from 2 to 1 instead of from 1 to 2 and if H_1 is equal to the former value of H_2, then

$$d^2F_{12} = d^2F_{21}.$$

If the apertures are large, integration can be performed on both sides and

$$F_{12} = F_{21},$$

which is the *reciprocity relation* of optics. It can

be shown to apply under the most general conditions (absorbing media, lens systems, etc.).

If $d\omega_2$ is the solid angle of the convergent lightcone with vertex at the center of dS_2, Eq. (3b) becomes

$$dD_2 = (H_2/\pi) \cos \theta_2 \, d\omega_2, \quad \text{(lumen m}^{-2}\text{)} \quad (3c)$$

which contains only quantities measured at 2 and which applies even when the medium is dissipative and inhomogeneous.

13. Small Source in a Perfect Medium

The word "perfect" in the above title is introduced to save repetition of the adjectives "homogeneous, isotropic, transparent (non-scattering), non-dissipative (no energy loss), and non-emittive." Consider a source at Q, having helios (H) and with dimensions small compared with PQ. Since the medium is perfect, there will be no scattering or absorption of radiant energy; and thus H will remain undiminished as the point P moves away from the sphere along any ray.

With a distance r between Q and P, the pharosage (flux density) at P is obtained directly from Eq. (6), or

$$D = (H/\pi)\omega \cos \psi, \quad \text{(lumen m}^{-2}\text{)} \quad (6b)$$

where ω is the solid angle of the convergent lightcone having its apex at P, and ψ is the angle of incidence. If S is the projected area of the source, Eq. (6b) becomes

$$D = [(HS/\pi)/r^2] \cos \psi, \quad \text{(lumen m}^{-2}\text{)} \quad (6c)$$

so the pharosage varies *inversely as the square of the distance*—the familiar inverse-square relation.

The **D** vector points along the line QP and has the magnitude $(HS/\pi)/r^2$. If $\mathbf{r}_1$ represents a unit vector in the direction QP then

$$\mathbf{D} = [(HS/\pi)/r^2]\mathbf{r}_1. \quad (6d)$$

The quantity (HS/π) in Eq. (6c) is, of course, the "intensity" ("candlepower") of the source. It may be urged that this quantity be written as a separate symbol and given a separate name. But such a procedure introduces an entirely unnecessary concept and complicates the basic system of concepts and units. In the early days of lighting, when all sources were small in dimensions, "intensity" was useful; but with the advent of the fluorescent lamp, the old idea has become practically valueless.

Under the new system, *distribution curves* for sources and luminaires will be plotted as *D vs. θ for a specified distance.* The pharosage for any other distance is then obtainable by well-known methods. The pharos (total flux) F from any luminaire is obtained by the usual methods (zonal method, Rousseau diagram, etc.) which are all based on the equation:

$$F = 2\pi r^2 \int_0^\pi D(\theta) \sin \theta d\theta, \quad \text{(lumen)} \quad (10)$$

where $D(\theta)$ is the pharosage *at any fixed distance r.*

14. Large Source in a Perfect Medium

Consider a large surface source S in a perfect medium. The convergent lightcone with apex at P has a solid angle ω which is fixed by the contour of S. For any elementary lightcone $d\omega$, within ω, the pharosage vector is, by Eq. (6b)

$$d\mathbf{D} = \mathbf{r}_1(H/\pi)d\omega,$$

where $\mathbf{r}_1$ is a unit vector along the axis of $d\omega$. For the whole lightcone,

$$\mathbf{D} = \frac{1}{\pi}\int_\omega \mathbf{r}_1 H d\omega. \quad (11)$$

The pharosage for any given surface can be written[18] in terms of the projected area $d\sigma''$ as

$$D_N = \frac{1}{\pi}\int_{\sigma''} H d\sigma''. \quad \text{(lumen m}^{-2}\text{)} \quad (12)$$

Equation (12) expresses the solid-angle method, one of the most powerful in photometrics. It applies to any surface source, uniform or non-uniform, perfectly diffusing or otherwise. It also applies without ambiguity to volume sources. (Note that unfortunate expressions such as "candles per square foot of sky" do not appear in the new system.) If the helios H is taken at point P, all effects of absorption, emission, and scattering are taken into account and Eq. (12) gives the true pharosage. In the special case of a perfect medium, H is constant along a given ray and thus may be considered at the source, at P, or anywhere else on the ray.

[18] Reference 8, p. 294.

For a case of a perfect medium and $H=$const. for all rays within the lightcone, Eq. (12) assumes the very simple form

$$D_N=\frac{H}{\pi}\int_{\sigma''} d\sigma''=H\sigma''/\pi. \quad \text{(lumen m}^{-2}\text{)} \qquad (12a)$$

An alternative way of calculating pharosage from large surfaces is the *plane-angle method*[1] which gives the equation:

$$\mathbf{D}=\frac{H}{2\pi}\int_{\alpha} d\boldsymbol{\alpha} \qquad (13)$$

for $H=$const. Here $d\boldsymbol{\alpha}$ is a vector which is normal to the surface of the convergent lightcone and whose magnitude is equal to the plane angle $d\alpha$ on the surface of the cone. For the special case of a source with n-sided polygonal boundary, Eq. (13) becomes

$$\mathbf{D}=\frac{H}{2\pi}\sum_{1}^{n}\boldsymbol{\alpha}_i. \qquad (13a)$$

One of the valuable assets of the **D** vector is its resolution into components. No matter how complicated the source, the pharosage for any surface with unit normal $\mathbf{N}_1$ is always

$$D_N=\mathbf{D}\cdot\mathbf{N}_1=D\cos\psi. \quad \text{(lumen m}^{-2}\text{)} \qquad (14)$$

Thus the necessity of performing separate integrations for sloping surfaces is entirely eliminated.

15. Interreflections

In a large number of illuminating engineering problems, the calculations of pharosage from the sources is not enough; for multiple reflections of light among the various surfaces are important. This is particularly true in the lighting of rooms. Thanks to the work of Buckley,[19] the problem is easily formulated as an *integral equation*. If the surfaces are perfectly diffusing and the medium is perfect,

$$H(s)=H_0(s)+\rho(s)\int_a^b K(s,t)H(t)dt, \qquad (15)$$

where $H(s)$ is the helios at point s of the enclosure. The point s is fixed at any arbitrary place on the surface, and t is allowed to vary over the entire surface (a to b). The reflection factor at s is $\rho(s)$, and $H_0(s)$ is the "initial" helios at s (value without interreflections). Equation (15) has been solved in a number of simple cases and has been applied recently to lightwells and to rectangular rooms.[20]

16. Two Media

Part of the radiant energy which reaches a smooth boundary between two media of different refractive indices is reflected, and the angle of reflection is equal to the angle of incidence. For a polished metal surface, experiment shows that the reflection factor ρ is not greatly affected by the angle of incidence θ_1. If the helios of a ray that reaches the surface is H_1, the helios of the reflected ray will be

$$H_2=\rho H_1, \quad \text{(blondel)} \qquad (16)$$

which applies to mirrors of any shape and shows that the *helios of the reflected ray is always less than the helios of the incident ray.*

If the mirror is curved properly, Eq. (16) continues to apply but the apparent *size* of the image is magnified. Under best conditions with a paraboloidal mirror, the entire reflector will be "flashed" and the pharosage at P will be

$$D_{\max}=H_2\omega_2=\rho H_1\omega_2, \quad \text{(lumen m}^{-2}\text{)} \qquad (17)$$

where $\omega_2=$solid angle subtended by the reflector (steradian),

$H_1=$helios of source (blondel).

Equation (16) applies also to the boundary between two insulating media, but ρ now becomes a function of the angle of incidence. The value of ρ for any value of θ can be calculated by use of the Fresnel equations. If the two insulating media are transparent, the helios of the transmitted ray is important. For a lens system, for instance, the helios of a ray from the lens is

$$H_2=\tau H_1, \quad \text{(blondel)} \qquad (18)$$

where $\tau=$transmission factor of the lens system for the given ray (numeric),

$H_1=$helios of the source (blondel).

[19] H. Buckley, "On the radiation from the inside of a circular cylinder," Phil. Mag. **4**, 753 (1927).

[20] Parry Moon, "On interreflections," J. Opt. Soc. Am. **30**, 195 (1940); "Interreflections in finite cylinders," J. Opt. Soc. Am. **31**, 223 (1941); "Interreflections in lightwells," J. Opt. Soc. Am. **31**, 301 (1941); "Interreflections in rooms," J. Opt. Soc. Am. **31**, 374 (1941).

Thus the helios of rays from the lens is always less than the helios of the source, though the solid angle ω_2 at P can be greatly increased by the lens over what it would be for a source of small dimensions. If the lens appears to be completely filled with light when viewed from P, the pharosage at a surface having the normal N is

$$D_N = H_2\omega_2 \cos\psi = \tau H_1\omega_2 \cos\psi, \text{ (lumen m}^{-2}\text{)} \quad (19)$$

where ψ = angle between N and the axis of the lightcone. Equations (17) and (19) apply rigorously only if the dimensions of the projector are small compared with the distance from it to P, a condition that is almost universally satisfied in practice.

17. Absorbing Media

For a medium that absorbs radiant energy but produces no diffusion, the helios varies exponentially along a ray in accordance with the Bouguer relation:

$$H = H_0 e^{-\alpha_1 r}, \text{ (blondel)} \quad (20)$$

where H_0 = helios of ray at $r = 0$, (blondel)
α_1 = attenuation factor of the medium (m^{-1}).

The pharosage produced by a small source in a perfect medium is given by Eq. (6d). If the medium absorbs radiant energy the expression is easily modified by use of Eq. (20) and becomes

$$D_N = [(HS/\pi)/r^2]e^{-\alpha_1 r}\cos\psi. \text{ (lumen m}^{-2}\text{)} \quad (21)$$

If the source dimensions are large compared with r, Eq. (12) is immediately applicable:

$$D_N = \frac{1}{\pi}\int_{\sigma''} H_P d\sigma'' = \frac{1}{\pi}\int_{\sigma''} H_0 e^{-\alpha_1 r} d\sigma'', \text{ (lumen m}^{-2}\text{)} \quad (22)$$

where H_P = helios at P (blondel).

18. Volume Sources

Consider a volume source, such as the sky or a quantity of vapor in an electric discharge lamp. At a given point P within the volume there will be a definite helios H along any given ray; and if the point P be moved a distance dr, the helios will change by the amount

$$dH = G dr,$$

where G is the heliosent (expressed in *blondels per meter*) at P along the given ray.

If P is outside the volume, the helios on a given ray becomes

$$H = \int_a^b G(r)dr, \text{ (blondel)} \quad (23)$$

if there is negligible absorption in the gas or vapor. If absorption is appreciable,

$$H = \int_a^b G(r)e^{-\alpha_1 r}dr \text{ (blondel)} \quad (23a)$$

and if $G(r) = \text{const.}$,

$$H = G/\alpha_1[e^{-\alpha_1 a} - e^{-\alpha_1 b}]. \text{ (blondel)} \quad (23b)$$

These equations lead to some interesting conclusions on the angular distributions from volume sources and from incandescent metals.[21]

19. Scattering Media

If the scattering is small, one may write approximately,

$$H = H_0 e^{-\alpha_2 r} \text{ (blondel)} \quad (24)$$

in conformity with Eq. (20). All the equations of Section 17 apply but with the coefficient α_2 in place of α_1. It should be noted, however, that the radiant energy which would be absorbed in the dissipative media is merely redirected in the scattering media.

When secondary scattering is important, as in the consideration of opal glasses, an integral equation is used. The distribution curve for scattered light depends on the size of scattering particle and on the wave-length and can be expressed as

$$\mu(\theta) = G(\theta)/D, \quad (25)$$

where θ is angle between the scattered ray and the exciting ray. The heliosent at P is expressed as an integral equation[22] of the Fredholm type:

$$G(P, \theta) = \pi\mu(\theta)\cdot D_0(P) + \int\int [\mu(r)e^{-\alpha r_2}]G(\theta, P)dr_2 d\omega_2.$$

[21] L. V. King, "Note on the cosine law of radiation," Phil. Mag. **23**, 237 (1912).
[22] L. V. King, "On the scattering and absorption of light in gaseous media," Phil. Trans. **212A**, 375 (1913).

When G is determined,

$$H = \int G(P, \theta) e^{-\alpha r_1} dr_1. \qquad (26)$$

When $\mu(\theta) = \text{const.}$ and G is a function of one variable, the foregoing equation reduces to the more useful form,

$$G(s) = \pi\mu D_s(s) - 2\pi\mu \int_0^t K(s, t) G(t) dt, \qquad (27)$$

where the kernel is

$K(s, t) = Ei(-\alpha_2 |s - t|)$, the exponential integral
$G(s)$ = heliosent at a fixed point s
$G(t)$ = heliosent at a variable point t
$D_s(s)$ = space-pharosage at s, neglecting scattering. Note that since light reaching s is scattered, irrespective of its original direction, D_s must be used, not D.

The first term of Eq. (27) represents direct scattering of the main beam of light, while the second term represents secondary scattering.

After $G(s)$ is obtained from Eq. (27), the helios along any ray is obtained by use of Eq. (26). If the medium absorbs as well as scatters, the same equations are used but with the general attenuation factor:

$$\alpha = \alpha_1 + \alpha_2 \qquad (28)$$

in place of α_1 or α_2. A simple extension includes also the volume source which scatters and absorbs.

20. SUMMARY

The antiquated photometric nomenclature in use today lacks generality and is unnecessarily complex. A new system is proposed which uses *six generalized concepts:*

(1) *Pharos* or luminous flux (F), expressed in *lumens.*
(2) *Pharosage* or flux-density (D), measured in *lumens per square meter.*
(3) *Helios* (H), a sort of generalized "brightness," expressed in *blondels.*
(4) Heliosent (G), a sort of "brightness gradient," expressed in *blondels per meter.*
(5) *Phos* (Q), called "quantity of light" in the old system, expressed in *lumen-seconds.*
(6) *Phosage* (W), usually called "exposure" in the past, expressed in *lumen-seconds per square meter.*

At least 90 percent of the usual calculations need only the first three concepts, and much can be done with the first two alone.

The same set of *concepts* is used in radiometry, where the lumen is replaced by the watt; and in the consideration of erythemal, bactericidal, fluorescent, photoelectric, photographic, and other effects. *In all cases the same six concepts are used, with the same concept names and symbols.* When necessary to prevent ambiguity, the various systems can be distinguished by subscripts on the symbols and by qualifying adjectives with the names. Different *units* are, of course, used in the various systems.

The introduction of new concepts provides an excellent opportunity for scrapping some of the old *names* which have caused so much confusion. The words "illumination," "brightness," and "intensity," for instance, are rejected as scientific names and can now be employed in their popular sense without fear of ambiguity. Similarly, the *units* are simplified and brought into the m.k.s. system.

The result is a simple, logical system, closely related to the remainder of physics, with concepts that are equally applicable to diffusing and scattering media, surface sources, and volume sources. The paper concludes with a cursory summary of geometrical photometrics, which is introduced to show that the entire subject can be handled without the introduction of further concepts.

In conclusion, there is nothing in the proposed system that requires it to be accepted or rejected in its entirety. If the reader finds the method of dimensions useful, he may accept that and reject the rest. If he feels that the generalized concepts are valuable but that the names are horrible, he may use the one and not the other. If he prefers the foot to the meter, there is nothing to prevent him from employing the proposed system with English units instead of metric. The writer of a book or a paper is at liberty to use as much or as little of the new system as he feels advisable. Time will tell what elements of the proposed system are valuable.

Book Review

The Retina. The Anatomy and the Histology of the Retina in Man, Ape, and Monkey, Including the Consideration of Visual Functions, the History of Physiological Optics, and the Histological Laboratory Technique. S. L. POLYAK. Pp. 607+x, Figs. 100. University of Chicago Press, Chicago, 1941. Price $10.00.

This is a book in the grand manner. Primarily, it records the author's researches on the fine structure of the retina—a task which required the preparation of innumerable retinal sections and the making of hundreds of drawings. However, the book contains not merely the details of fine anatomy; its subject matter covers history, optics, and physiology as well. The University of Chicago has published the final result in the style which it deserves. It is a large book, large in format and large in spirit; it contains about 600 closely printed pages, each $7\frac{1}{2}\times10\frac{1}{4}$ inches.

The volume is divided into five sections differing in length and in importance. Part I deals with methods. Its five chapters occupy about 85 pages, and are concerned with the theory and practice of anatomical and histological investigation of the retina, and of the visual pathways in the brain. Standard methods of tissue fixation, staining, etc., are presented and critically evaluated, and the results of much research into new methods by the author are included.

Part II contains the history of physiological optics from antiquity until after the Renaissance, and occupies nearly 50 pages. About half of this section deals with Arabian contributions made during the dark European days when the Arabs were the sole possessors of scientific knowledge. The section is illustrated with reproductions of ancient diagrams, and reveals the fascinating combination of hard sense and artistic nonsense from which arose the physiological optics of today.

Part III is a history and criticism of the microscopic aspects of the retina and of modern notions of its structure and function. It is short and leads quickly to Part IV which contains the real meat of the book. This section has 16 chapters, occupies about 180 pages, and is illustrated by a profusion of handsome and meticulous drawings. Each aspect and structure of the retina has its full share of space and attention. The yellow spot and the fovea, the periphery and the nerve fibers, the rods and the cones, the bipolar cells, the ganglion cells, the neuroglia, the amacrine cells, all come in for full and detailed treatment.

It is dangerous to summarize 180 pages in a few paragraphs, particularly when much detailed description is included in them. Yet the author has been so systematic that the task is simplified by virtue of Part V, which is an interpretative synthesis of microscopic structure and visual function. This part will be most read by physiologists and physicists interested in vision.

The gist of the book is that visual function and visual structure are intimately related, and that these relations are reasonable. The retina is made up of a number of types of nerve cells woven together into a pattern. According to Polyak, there are at least 13 distinct types of these neurons, probably many more. There are two varieties of photoreceptors, namely, the rods and cones. There are horizontal cells, at least two types of amacrine cells, three or four varieties of bipolar cells, and five or six types of ganglion cells. These elements are arranged in three layers. In the first the light is received by the photoreceptor cells; in the second the impulses from the photoreceptor cells are analyzed and associated by the bipolar cells, the horizontal cells, and some of the amacrine cells; in the third the final impulses from all of these are integrated in the ganglion cells which convey them to the brain. Over thirty types of connection among these various cells can be recognized; the connections are complex but apparently stable.

The most clearly recognized structures are the foveal cones, the midget bipolars, and the midget ganglions, which are related one to the other by single connections. They are thus responsible for the highest degree of visual acuity in daylight vision. Outside of this central region there seem to be many more diffuse combinations of elements which are responsible not only for the poor acuity of peripheral daylight vision, but for the poor acuity of the peripheral night vision. There would even seem to be structures which are concerned with the summing of effects due to the activity of both rods and cones under certain conditions.

The bibliography is witness to the labor and erudition incorporated into the book. It runs to 129 pages of fine print, and ranges over the whole subject from history to geography, from physics to psychology, and from the earliest days to the last moment before publication. Following it is the index, which itself occupies 22 pages, each with three columns on it.

The last section of the book is 100 pages of illustrations made up of photographs, maps, and of three kinds of drawings. Of the latter, the first kind is historical; the second is detailed statement about specific structures; the third is diagrammatic reconstruction of these details in terms of the author's knowledge and experience, which amount almost to an intellectual intuition. One regrets the complete segregation of these illustrations, because it involves the constant turning back and forth from text to drawings during reading. This is the tradition of an anatomical memoir, but it is a nuisance just the same.

One cannot criticize a book of this nature; one can only be grateful for it. This does not mean that it is free from controversial material or that it does not contain errors. These, however, are trivial by comparison with the magnitude of the work. It is a monumental contribution, representing an unique combination of industry, erudition, imagination, and artistry.

SELIG HECHT
Columbia University

Minutes of the Nineteenth Meeting of the Board of Directors of the Optical Society of America, Incorporated

ROCHESTER, NEW YORK, FEBRUARY 14, 1942

IN addition to the transaction of routine business and the receiving of reports of committees and representatives, the following items of general interest to members of the Society were taken up.

Announcements by Secretary

Results of letter ballots:

1. Approval of resolution to accept resignation of Henry F. Kurtz as Treasurer, effective December 31, 1941.
2. Approval of appointment of the following Associate Editors for a term ending December 31, 1947:

R. B. BARNES,	PARRY MOON,
E. O. HULBURT,	HANS MUELLER,
H. E. IVES,	A. H. PFUND,
D. B. JUDD,	T. A. WRIGHT.

3. Approval of election of W. W. Graeper as Treasurer to fill the unexpired term of H. F. Kurtz, resigned.
4. Approval of resolution cancelling plans for February, 1942 O. S. A. meeting.

The following Committees and Representatives were appointed:

1. Ives Medal Committee
   W. E. FORSYTHE, *Chairman*
   H. K. HARTLINE, PARRY MOON,
   R. KINGSLAKE, S. H. NEWHALL.
2. Membership Committee
   FRED PERRIN, *Chairman*
   C. W. GARTLEIN, A. W. KENNEY,
   G. S. MONK.
3. Committee on Transfer to Regular Membership
   W. E. FORSYTHE, *Chairman*
   G. H. GLIDDON, E. O. HULBURT.
4. Committe on Honorary Membership
   A. H. PFUND, *Chairman*
   G. H. GLIDDON, ELMER HUTCHISSON,
   W. F. MEGGERS.
5. Auditors
   CARL BAUSCH, FRED PERRIN.
6. Representative on the Council of the A.A.A.S., for a term to expire in February, 1944
   W. E. FORSYTHE.
7. Representative on Division of Physical Sciences of National Research Council for a term to expire on June 30, 1945
   A. H. PFUND
8. Program Committee for 1942 Summer Meeting
   G. R. HARRISON, *Chairman*
   DOROTHY NICKERSON, R. A. SAWYER.

Membership

The Secretary reported informally that between January 1, 1942, and February 14, 1942, there were 24 new members, 2 reinstatements, and 6 resignations.

Annual Meeting of the Society

It was voted "To hold the annual meeting in 1942 at the Hotel Pennsylvania in New York City at a time to be decided by the Secretary after exploring the plans of the other Founder Societies of the American Institute of Physics."

ARTHUR C. HARDY, *Secretary*

Report of the Editor of Publications

Statement of Operations of the Journal of the Optical Society of America for the Year Ending December 31, 1941

Income

Non-Member Subscriptions		$5,056.36
Net Income from Published Articles		2,009.64
Net Income, Cumulative Index		10.06
Net Income from Sale of Back Numbers		763.17
Rockefeller Foundation Grant for 1941		766.27
Total Income Exclusive of Member Subscriptions		$ 8,605.50

Expense

Printing and Mailing		$7,954.13	
Engraving		1,487.80	
Editorial Mechanics:			
Salaries	$799.25		
Office Expense	227.97	1,027.22	
Subscription Expense:			
Salaries	$910.91		
Office Expense	255.49	1,166.40	
Other Expenses:			
Auditing, Insurance, and Miscellaneous		322.03	
Editorial Office (Cambridge):			
Salaries	$1,000.00		
Expenses	84.11		
		1,084.11	
Total Cost of Editing and Publishing Journal			$13,041.69
Net Cost of Operating Journal and Furnishing It to Members			$ 4,436.19

Number of Pages Published	*1941*	*1940*	*1939*	*1938*
Text and Index	774	666	550	508
Covers and Front Material	72	72	72	56
Total	846	738	622	564

(Signed) G. R. Harrison, *Editor*

Annual Report of the Treasurer of the Optical Society of America for the Fiscal Year 1941

CASH TRANSACTIONS JANUARY 1, 1941 TO DECEMBER 31, 1941

Receipts

Dues	$4,290.75	
Dues in advance	3,793.20	
Interest on unallocated securities	926.00	
Interest on bank balance	16.50	
Interest on Ives Medal Fund Bonds	15.00	
		$ 9,041.45

Disbursements

Secretary's expense	$1,475.43	
Secretary's travel expense	24.50	
Treasurer's expense	387.00	
President's expense	20.15	
Journal publication expense	8,614.52	
Journal editorial expense	1,300.00	
Membership Committee expense	53.55	
Contingencies	11.64	
Ives Medal Fund expense	19.44	
Local Committee expense	4.85	
Specially Appropriated Expenditures		
Inter-Society Color Council dues	25.00	
U. S. Nat. Com. of Int. Com. on Ill.	100.00	
Colorimetry Committee expense	37.50	
		$12,073.58
Excess of disbursements over receipts		$ 3,032.13
Balances—December 31, 1940		
Unallocated cash in bank	$4,446.11	
Ives Medal Fund interest	112.93	
A. Lomb Fund interest	227.91	
Local Committee Fund	182.81	$ 4,969.76
Cash Balance, December 31, 1941		$ 1,937.63

Ives Medal Fund

Income

Principal sum	$ 500.00	
Cash interest balance, January 1, 1941	112.93	
Bond interest accrued during 1941	15.00	
		$ 627.93

Disbursements

For Medal for Selig Hecht	$ 19.44
Balance, December 31, 1941	$ 608.49

Note: The principal sum of $500.00 is invested in the United States Treasury 3¼ percent certificates. They are included in the bonds reported in the accompanying Investment Statement.

Adolph Lomb Memorial Fund

Income

Proceeds on sale of Dominion of Canada 3¼% bonds, less commissions, taxes, etc.	$1,693.46	
Bank interest on above cash	13.21	
Balance interest, December 31, 1941	227.91	
		$1,934.58
Disbursements		
. . . . .		. . . . .
Balance, December 31, 1941		$1,934.58
Principal Fund		
Balance, December 31, 1941	$1,934.58	
Special Appropriation from O.S.A.	68.55	
		$2,003.13
Disbursements		
2,000 U. S. Treasury Certificates	$2,000.00	
Accrued interest paid on Treasury Certificates	3.13	
		$2,003.13
Cash Balance, December 31, 1941		$ 00.00

Local Committee Fund

Income

Cash balance, January 1, 1941	$ 182.81
Disbursements	
Expenses connected with 1941 meetings	$ 4.85
Balance, December 31, 1941	$ 177.96

Securities Held by the Security Trust Company of Rochester as Agent for the Optical Society of America, Inc.

	Book Value	1941 Return	Rate Against Book Value
Bonds			
$7,000 Atchison, Topeka & Santa Fe 4% General Mortgage 4% Bonds			
Received 4–11–33	$ 7,000.00	$ 280.00	4%
$5,600 U.S.A. Treasury 3¼% Bonds			
Bought @ average $99.951	5,625.67	182.00	3.23%
$10,000 U.S.A. Treasury 2½% Bonds			
Bought 12–13–41 @ 100	10,001.31	240.00	2.50%
Total Bonds	$22,626.98	$ 702.00	3.10%
Stocks			
10 shares Eastman Kodak Common			
Bought 9–22–36 @ 172⅝	$ 1,718.19	$ 60.00	3.5 %
65 shares General Electric Common			
Bought 9–21–36, 40 shares @ 46½	1,871.35	102.00	4.00%
Bought 12–2–41, 25 shares @ 26⅝	672.88		
35 shares Kennecott Copper Corp.			
Bought 9–21–36 @ 49⅛	1,729.53	148.75	8.65%
Total Stocks	$ 5,991.95	$ 310.75	5.18%
Total Investments	$28,618.93	$1,012.75	3.6 %

The undersigned, having been duly appointed to audit the books of the Treasurer of the Optical Society of America, Inc., from January 1, 1941 to December 31, 1941, hereby certify that the Treasurer's report of receipts, disbursements, and investments is correct as shown by records, vouchers, bank statements, etc.

(Signed) Carl L. Bausch, C. W. Frederick, *Auditors*

Annual Report of the Secretary of the Optical Society of America, Inc. for the Calendar Year 1941

Membership Record

January 1, 1941 to January 1, 1942

	Honorary	Regular Annual Payment	Regular Life Payment	Associate Individual Annual Payment	Associate Corporation	Emeritus	Student	Total
Membership as of record in the books of the Secretary 1-1-41	4	406	6	445	10	0	0	871
Gains during 1941								
By election as of 1–1–41	0	0	0	149	5	0	3	157
By election as of 1–1–42	0	0	0	37	0	0	6	43
By reinstatement as of 1–1–41	0	2	0	3	0	13	0	18
By transfer 10–24–41 as of 1–1–42	0	77	0	0	0	0	0	77
Losses during 1941								
By death	0	4	0	2	0	0	0	6
By resignation as of 1–1–41	0	3	0	0	0	0	0	3
By resignation as of 12–31–41	0	5	0	11	0	0	0	16
By transfer 10–24–41 as of 1–1–42	0	0	0	77	0	0	0	77
By separation for non-payment as of 1–1–41	0	10	0	10	0	0	0	20
Membership as of record 1-1-42	4	463	6	534	15	13	9	1044

Elected during 1941 as of January 1, 1941

Bailey, Ralph W. (1463 A)
Baldwin, H. Wallace (1505 A)
Bamford, Harry S. (1467 A)
Barton, Charles J. (1522 A)
Bateson, Sydney (1631 A)
Beckley, Hugh (1578 A)
Bell & Howell Company (1511 AC)
Bendix Aviation Corp. (1530 AC)
Berger, C. E. (1572 A)
Bernstein, Harry S. (1501 A)
Beutler, H. G. (1611 A)
Birren, Faber (1497 A)
Blodgett, Katharine Burr (1515 A)
Bloomsburgh, R. A. (1459 A)
Brody, James K. (1464 A)
Bubb, Frank W. (1521 A)
Buc, George L. (1580 A)
Burian, Hermann M. (1601 A)
Burton, Allan L. (1503 A)
Butler, Keith Huestis (1633 A)
Cameron, Donald B. (1566 A)
Campbell, Jean I. (1531 A)
Canning, Robert A. (1482 A)
Churchill, J. R. (1581 A)
Clark, E. P. (1519 A)
Clark, Orrin H. (1474 A)
Corliss, Charles H. (1574 A)
Countryman, M. Alden (1520 A)
Craig, William M. (1644 A)
Darby, Hugh H. (1549 A)
Dieke, G. H. (1634 A)
Driscoll, Walter G. (1582 A)
Dubray, Joseph A. (1491 A)
Duffendack, O. S. (1488 A)
Dunlop, E. C. (1600 A)
Durand, Eric (1550 A)
Dutton, William Leonard (1470 A)
Eastman Kodak Company (1536 AC)
Elliott, Robert M. (1534 A)
Ells, Victor R. (1509 A)
Englis, Duane T. (1567 A)
Essig, Sanford F. (1535 A)
Fairchild Aviation Corp. (1564 AC)
Fanter, Walter R. (1514 A)
Filler, Aaron S. (1504 A)
Flory, Louis Paul (1635 A)
Fogle, Marlin E. (1544 A)
Foor, S. Wayne (1573 A)
Forgeng, William D. (1570 A)
Forsbergh, P. W., Jr. (1622 S)
Fred, Mark S. (1499 A)
Friar, Lawrence Brown (1555 A)
Green, Ernest A. (1517 A)
Grimson, Samuel B. (1476 A)
Grossman, Harold Henry (1636 A)
Guiney, John J. (1468 A)
Halverson, Gilbert (1469 A)
Hardy, LeGrand H. (1480 A)
Hargitt, Thomas F. (1506 A)
Harvey, James E. (1481 A)
Herman, William F. (1638 S)
Hesling, Francis Mills (1462 A)
Hewitt, Joseph (1560 A)
Hineline, Harris D. (1643 A)
Hoffman, Olive (1587 A)
Hulbert, Henry S. (1490 A)
Hurvich, Leo M. (1492 A)
Jenkins, Francis Arthur (1539 A)
Jolliff, E. Corwith (1584 A)
Kallmann, Hilde K. (1583 A)
Karlin, Henry M. (1588 A)
Kavanagh, Arthur J. (1507 A)
King, Carl (1585 A)
Krewer, Semyon E. (1608 A)
Lamb, Frances W. (1484 A)
LaMotte, John D. (1595 A)
Laufer, Maurice K. (1471 A)
Law, William S. (1518 A)

Lawton, L. M. (1571 A)
Lewis, Robert Edward (1475 A)
Little, Elbert Payson (1554 A)
Lott, Wreal L. (1586 A)
Lovins, Gerald H. (1545 A)
Lyons, Frank B. (1589 A)
MacLeod, Robert B. (1562 A)
Magel, Theodore T. (1528 A)
Mahan, A. I. (1540 A)
Malpica, J. T. Mireles (1516 A)
Maurer, John A. (1605 A)
Mayer, Charles L. (1532 A)
McFarland, Ross A. (1526 A)
McLeod, John Henry (1472 A)
Mellor, Louis (1558 A)
Miller, Elmer S. (1500 A)
Milligan, William Edgar (1565 A)
Milne, Gordon Gladstone (1512 A)
Moffatt, Edward H. (1551 A)
Molnar, Julius P. (1465 A)
Mrgudich, J. N. (1546 A)
Munch, Ralph H. (1568 A)
National Carbon Co. (1552 AC)
Nicklay, A. J. (1597 A)
O'Connor, Robert Thomas (1559 A)
Orr, James McPhail (1466 A)
Oshry, Howard I. (1590 A)
Pearson, Frederick B. (1494 A)
Perry, Donald M. (1485 A)
Pickering, R. D. (1553 A)
Pinker, Ray H. (1483 A)
Platt, John R. (1496 A)
Pryor, Paul L. (1508 A)
Rahr, Frederic H. (1606 A)
Ramsay, Bertrand P. (1461 A)
Reardon, Joseph D. (1487 A)
Renfrew, A. S. (1538 A)
Reuter, Frederic W., Jr. (1479 A)
Richards, Albert G. (1486 A)
Rohrbaugh, John H. (1477 A)
Ryan, Charles E. (1513 A)
Schecter, Harry (1523 A)
Scholz, Louis A. (1473 A)
Schroeder, Jacob (1579 A)
Severance, Donald P. (1493 A)
Shepard, Anna O. (1541 A)
Sheppard, Ernest (1495 A)
Sherry, John M. (1557 A)
Shurkus, Albert A. (1592 A)
Snavely, Benjamin L. (1498 A)
Speyer, Edward M. (1529 A)
Steinhardt, Lawrence R. (1598 A)
Stevens, Eli (1502 A)
Strong, John (1599 A)
Sturkey, Lorenzo (1596 A)
Suga, Taro (1594 A)
Sullivan, Francis J. (1547 A)
Sullivan, Royal A. (1569 A)
Sweet, Monroe Hamilton (1537 A)
Taylor, Edward Wilfred (1577 A)
Thomson, Kenneth B. (1478 A)
Towle, Edward C. (1525 A)
Troutman, Mary C. (1533 A)
Vandivere, E. (1575 A)
Waldbauer, Louis (1542 A)
Walrath, E. K. (1524 A)
Warren, Winthrop D. (1527 A)
Watanabe, Kenichi (1561 A)
Watson, James S., Jr. (1458 A)
Weiss, Richard A. (1489 A)
Wells, Franklin H. (1593 A)
White, Harvey E. (1543 A)
Whitmore, Keith E. (1620 S)
Wilkie, John B. (1576 A)
Williams, Charles R. (1460 A)
Wilson, Mabel F. (1563 A)
Wing, Howard E. (1510 A)
Wolfe, Ralph A. (1591 A)
Youngkrantz, Howard R. (1548 A)

Elected during 1941 as of January 1, 1942

Altman, Joseph H. (1641 S)
Armstrong, David W. (1615 A)
Bartelt, John A. (1626 A)
Bartley, S. Howard (1618 A)
Bennett, Clarence E. (1632 A)
Carl, Howard F. (1660 A)
Cole, Peter A. (1616 A)
Cook, E. B. (1646 A)
Fisher, Russell A. (1645 A)
Fitter, Charles F., Jr. (1603 A)
Hammond, Harry K., III (1640 A)
Harper, David C. (1617 A)
Hartwick, Albert G. (1614 A)
Hemmendinger, Henry (1627 A)
Hornbeck, John A. (1628 A)
Hoyt, Gordon D. (1602 A)
Ingle, George W. (1651 A)
Ireland, Andrew T. (1656 A)
Kelly, Joseph B. (1639 S)
Kohler, Wolfgang (1647 A)
Liddel, Urner (1657 A)
Little, Edward M. (1619 A)
Lyons, Sanford C. (1607 A)
MacPherson, H. G. (1612 A)
Miles, John (1642 A)
Mueller, Hans (1652 A)
Shankland, Robert S. (1556 A)
Sheetz, John, 3rd. (1624 S)
Silvertooth, E. Wilbur (1637 A)
Skeffington, Mary Jane (1649 A)
Smith, Paul E., Jr. (1629 A)
States, M. N. (1610 A)
Staunton, J. J. J. (1654 A)
Steele, Westbrook (1613 A)
Timoshenko, Gregory S. (1653 A)
Tyler, John E. (1609 A)
Urbain, Walter M. (1604 A)
Warren, A. B. (1650 A)
Weitzenhoffer, Andre M. (1623 S)
Williamson, Betty (1630 A)
Wood, Donald L. (1625 A)
Yevick, George J. (1621 S)
Zeitz, Carl (1655 S)

Elected to Regular Membership by Action of the Board of Directors, October 24, 1941, effective as of January 1, 1942

Allen, A. J. (1258 A)
Bacon, J. F. (1267 A)
Barnes, R. B. (1425 A)
Beck, C. A. (1406 A)
Benford, J. R. (997 A)
Berger, C. E. (1572 A)
Blodgett, K. B. (1515 A)
Brode, W. R. (1375 A)
Brown, R. H. (1246 A)
Carr, E. P. (1292 A)
Cartwright, C. H. (1248 A)
Child, G. P. (1426 A)
Cholak, J. (1427 A)
Cooke, H. L. (1398 A)
Crowe, M. O'L. (1428 A)
Darby, H. H. (1549 A)
Dietert, H. W. (1378 A)
Drabkin, D. L. (1379 A)
Dubray, J. A. (1491 A)
Dudley, B. (1084 A)
Duffendack, O. S. (1488 A)
Elliott, R. M. (1534 A)
Evans, C. H. (1187 A)
Flint, E. F. (1112 A)
French, H. S. (1305 A)
Furman, N. H. (1402 A)
Glenn, J. J. (991 A)
Glover, A. M. (1192 A)
Griggs, M. A. (1308 A)
Hardy, LeG. H. (1480 A)
Hasler, M. F. (1310 A)
Hebo, H. (1131 A)
Hess, T. M. (1381 A)
Holway, A. H. (1235 A)
Jaycox, E. K. (1316 A)
Jenkins, F. A. (1539 A)
Jones, F. L. (1238 A)
Koch, W. R. (1323 A)
Kruper, A. P. (1181 A)

Elected to Regular Membership by Action of the Board of Directors, October 24, 1941, effective as of January 1, 1942 (continued)

Lamb, F. W. (1484 A)
Langstroth, G. O. (1272 A)
Leighton, P. A. (1273 A)
Macbeth, N. (1087 A)
MacLeod, R. B. (1562 A)
Malpica, J. T. M. (1516 A)
McFarland, R. A. (1526 A)
McLellan, R. D. (1329 A)
McLeod, J. H. (1472 A)
Mellon, M. G. (1330 A)
Melvin, E. H. (1331 A)
Merrill, D. P. (1249 A)
Molnar, J. P. (1465 A)
Neuhaus, C. J. (1443 A)
Osborn, R. H. (1097 A)
Overhage, C. F. J. (1093 A)
Paul, F. W. (1247 A)
Rankin, C. W. (890 A)
Reinheimmer, H. H. (1343 A)
Ruehle, A. E. (1347 A)
Rule, J. T. (1433 A)
Sampson, A. M. (1348 A)
Shaw, R. W. (1255 A)
Shenstone, A. G. (1350 A)
Slavin, M. (1354 A)
Stone, F. M. (1357 A)
Straat, H. W. (1251 A)
Strock, L. W. (1387 A)
Thomson, K. B. (1478 A)
Urbach, C. (1455 A)
Vincent, H. B. (1066 A)
Weeks, D. W. (1363 A)
Wolfe, R. N. (1195 A)
Wooters, G. C. (1415 A)
Work, H. (1367 A)
Wright, T. A. (1369 A)
Wurzburg, F. L., Jr. (1050 A)
Ziegler, G. E. (1372 A)

Reinstatements during 1941 as of January 1, 1941

Crew, Henry (62 RE)
Davis, Bergen (411 RE)
Estey, Roger S. (848 R)
Forrest, John W. (900 R)
Gage, S. H. (710 RE)
Gale, Henry (143 RE)
Hodge, Percy (475 RE)
Ives, James E. (316 RE)
Kerr, C. H. (14 RE)
Pelletier, P. E. (1144 A)
Randall, H. M. (146 RE)
Rankin, Charles W. (890 A)
Ruedy, Richard (771 A)
Sharp, C (105 RE)
Silberstein, L. (170 RE)
Southall, J. P. C. (27 RE)
Stickney, G. H. (222 RE)
Thwing, C. B. (144 RE)

Deaths during 1941

Hower, Harry S. (140 R) (Died on October 10, 1941)
Miller, Dayton C. (464 R) (Died on February 22, 1941)
Miller, Elmer S. (1500 A) (Died on June 11, 1941)
Sparrow, Carroll M. (641 R) (Died on August 30, 1941)
Stebbins, Theodore (1413 A) (Died on October 14, 1941)
Wick, Francis G. (558 R) (Died on June 15, 1941)

Resignations during 1941 as of January 1, 1941

Randall, H. M. (146 R)
Sheppard, S. E. (401 R)
Southall, J. P. C. (27 R)

Resignations during 1941 as of December 31, 1941

Babcock, F. A. (1172 A)
Bailey, Ralph W. (1463 A)
Carter, Edna (755 R)
Dutton, William L. (1470 A)
Hanson, A. R. (1221 A)
Harting, Hans (308 R)
Hustrulid, Andrew (1024 R)
Jones, Granville R. (1079 A)
Killian, Thomas J. (969 A)
Lindberg, Ramon I. (1274 A)
Murray, William M., Jr. (1335 A)
Neumueller, Julius F. (1030 R)
Page, Leigh (998 R)
Shepard, Anna O. (1541 A)
Towle, E. C. (1525 A)
Tucker, C. W. (1361 A)

(Signed) ARTHUR C. HARDY, *Secretary*